ON THE NATURE OF THINGS

A Universe Far Greater...

A Prelude to a Universe Far Greater:

Chapter 1: Extreme Scales of Time, Space, and Matter

The scale of the universe is far beyond human imagination. To even grasp it, we build scale models of objects in the universe and bring them to the everyday scale so we can understand them. There are three ways to do this, and each way or type of scale is defined by units of measurement. There are elapsed times, distances in space, and amounts of mass.

Before we begin, let's first understand orders of magnitude. Take one million marbles, as an example. We have a unit of measurement, the number of marbles. I could write this as "1,000,000 marbles", or as "1 * 10^6 marbles", or even as "one million marbles". If I define this as a mega-marble it means that I have now simplified this setup, by introducing a new unit of measurement. Since numbers can get very huge very fast, it becomes useful to define a new system of prefixes for our numbers. We have already met one prefix, mega, which means million. There are others too. A marble is 1 marble. A kilo-marble is 1,000 marbles. A mega-marble is 1,000 kilo-marbles. A gigamarble is 1,000 mega-marbles. A tera-marble is 1,000 giga-marbles. A peta-marble is 1,000 tera-marbles. This pattern continues on, by multiplying by one thousand every time. If we divided by a thousand instead of multiplying, we arrive at the following units of, milli-marbles, micro-marbles, nano-marbles, pico-marbles, and femto-marbles.

Now with this in mind, imagine two marbles floating in the void. Time runs at the same universal rate for both marbles. Both marbles each maintain their motion, as they both independently travel in straight lines with a constant speed. The two marbles both have definite positions as well as definite velocities. This all makes perfect sense. In order to define what is going on, we introduce a system of units that measure time, space, and matter.

Time controls the evolution of the marbles. This is because, since the marbles are moving, their positions change over time. At every moment or snapshot of time, there is a unique configuration of our marbles. To specify which configuration we are talking about, it becomes useful to introduce a clock that measures which snapshot we are in. Playing each snapshot back in sequence, moment after moment, we recover the evolution of the scene. This is just like the pages in a flip book or the frames of film in a movie projector. The clock time is universal and we count the frames with a new unit of measurement, the second.

The Second is defined as follows: A full day by definition lasts 86,400 seconds. A minute is 60 seconds. An hour is 60 minutes. A day is then 24 hours. One week is 7 days. One month is 4 and 1/3 weeks. A year is 12 months. A decade is 10 years. A generation is 3 decades. Similarly, a kilosecond is one thousand seconds, and a millisecond is a thousandth of a second.

Space is measured by using a three dimensional coordinate grid. The X dimension runs from left to right. Next, the Y dimension goes from the back to the front. Lastly,

the Z dimension points straight up. By measuring these three numbers, we can find the position of any marble. This is just like the addresses in a city, which uses the street numbers, avenue numbers, and floor numbers. We thus define the meter as our unit of distance in space.

The Meter is defined as follows: Walking in a straight line from the equator to the north pole is by definition 10 million meters. One centimeter is 0.01 meters. An inch is 2.54 centimeters. A foot is 12 inches. A yard is 3 feet. A mile is 1,760 yards. Similarly, a kilometer is one thousand meters, and a millimeter is a thousandth of a meter.

The amount of matter in a marble measures its resistance to a change in its motion. Marbles like everything else are made of fundamental indivisible particles, called atoms. These atoms behave just like tiny identical marbles, since they too, like everything else, maintain their state of motion. This means that the amount of matter in a marble maintaining its motion, is then just the total number of atoms in that marble, which are all maintaining their motions. Similarly for two or more marbles, the total amount of matter is just the total number of atoms in all of our marbles. We call the amount of matter inherited to an object, as its mass, and is measured in grams.

The Gram is defined as follows: By definition, a cubic centimeter of water has a mass of a gram. One ounce is 28.349523125 grams. A pound is 16 ounces. A ton is 2 thousand pounds. Similarly, a kilogram is one thousand grams, and a milligram is a thousandth of a gram.

As it turns out, it doesn't matter what units of measurement we use to describe the marbles, the result is always the same. As an example, we could define a totally new system of units with hours, miles, and pounds, instead of seconds, meters, and grams. Even though the numbers will be different, the physics of our two marbles will be exactly identical. This is true, even in different setups. We can therefore get rid of our units of measurement, and claim that the physics of the marbles will work regardless. With the physics of our two marbles, it seems like our lives are also a linear mechanical progression, because like the marbles, we too are made of atoms. We then conclude that our clockwork universe is made up of atoms meaninglessly drifting in the void, and is completely deterministic. This is sadly just the way it is. Or is it?

A Scale Compressed Version of Reality

Imagine a toy scale universe where all of the extreme scales are not so extreme. All of the things outside of our day to day experience will become obvious. Using meters, grams, and seconds, here is an example. Imagine a real life scenario that evolves over 1 minute and 40 seconds. The toy scale version will have it take place in 2 seconds. Conversely, if a buzzer sound vibrates with 100 cycles every second in real life, the toy scale version will vibrate with 2 cycles per second. Instead of 1 centimeter in reality we

have 50 centimeters in the toy scale. Instead of 100 meters, we have 2 meters. Instead of 100 grams, we would have 2 grams, and instead of 0.01 grams, we'd have 0.5 grams.

The rule I am using is simple. To any unit of measurement, even composite units containing many powers of meters, grams, and seconds, we always scale compress powers of a hundred to powers of two. Here is a table that shows how this happens:

#	**2^#**	**100^#**
-3	0.125	0.000001
-2	0.25	0.0001
-1	0.5	0.01
0	1	1
1	2	100
2	4	10,000
3	8	1,000,000

The # column is the exponent that tells us which domain of reality we are in, macro, or micro. The powers of two column denoted by 2^#, is the result of a measurement done in the toy scale universe. Whereas, the 100^# are the powers of one hundred, which explode toward infinity, or implode close to zero. We can see that a unit of measurement with a value of 0.5 or a half, in the toy scale universe that is scale compressed, maps exactly onto 0.01 or one percent in real life. This is what allows one to easily grasp the relative scales of things in nature.

Since this expands our horizons on to these extreme scales we mentioned earlier in the book, it becomes interesting to find out what kinds of physics will come into play at such scales? So far, we don't know what happens at such extremes. Could it be that no new physics shows up, and everything about our two marbles scales perfectly? This would mean that every scale is perfect and we do indeed live in a mechanical linear progression, as every measurement will be exact.

The other possibility is more exciting, and devastating to our common sense worldview. If new physics does appear, what would it be like to experience it first hand in the toy scale universe? As it turns out both our universe and the toy scale universe both share this feature of introducing new physics at it's perimeter. And, by boundary, I don't simply mean that the universe is finite, as space, time, and matter, could go on forever. This is thinking linearly, and additively. As far we know there is no end in this sense.

However, the boundary I am talking about here is that of scale. The universe likely is infinite, but our view of it is finite. By thinking in a logarithmic fashion, we hit a brick wall, where the new physics sets a scale that one cannot pass. It is a great excersize to think of it, not as a scale factor being limited, but as the scale of the limiting factor itself. Not because our senses are bad, but because new physics does appear that constrains our view no matter how good our vision of it is.

The toy scale universe is a perfect example of this. It brings these limits very close to our everyday scale of things. Our view of scales thus expands way out to both the infinite and infinitesimal, all at once without causing confusion about big or small numbers. It is a great start at learning new physics, because at these scales everything becomes intuitive.

Like the last table, we are using both powers of 2 and powers of 100. But here we only list the exponents, so be careful. We can read off the first few rows of both toy scale and real scale. There is the scale where all limits of new physics interact, we call these new physics conepts: C, G, and H. Don't worry what they are yet, but if you feel up to the task, you might guess them based on which scales they limit, and by how much.

Take the time scale of 5 for example. If this were in seconds after the new year, the toy scale would be just 2^5 or 32 seconds since the common era began. For the real scale universe, this would correspond to year 316 AD, the date would be November 20th, which is on the 3rd day of the week, and the time of day: 5:46 PM and 40 seconds. Guess the elapsed time? It would be 100^5 seconds, otherwise put 10 billion seconds, or in science terms 10 Giga-seconds.

So clearly the toy scale universe makes a scale compressed universe intuitive and brings complex physics into the everyday. The table also includes the physics required to understand the happenings at any scale of the universe considered. A rule of thumb is that if your close to a limiting factor, you'd better include the physics cooresponding to every limit you are close in scale to. Here is the rest of the table.

time scale	**space scale**	**matter scale**	
2^#	2^#	2^#	CGH physics for toy scale
100^#	100^#	100^#	real scale physics required
0	0	0	CGH
5	3	-1	GH
5	5	5	CG
5	5	-5	CH
10	6	-2	GH
10	8	4	G
10	8	-6	H
10	10	10	CG
10	10	0	C
10	10	-10	CH
15	9	-3	GH
15	11	3	G
15	11	-7	H
15	13	9	G
15	13	-1	#

15	13	-11	H
15	15	15	CG
15	15	5	C
15	15	-5	C
15	15	-15	CH
20	12	-4	GH
20	14	2	G
20	14	-8	H
20	16	8	G
20	16	-2	#
20	16	-12	H
20	18	14	G
20	18	4	#
20	18	-6	#
20	18	-16	H
20	20	20	CG
20	20	10	C
20	20	0	C
20	20	-10	C
20	20	-20	CH
25	15	-5	GH
25	17	1	G
25	17	-9	H
25	19	7	G
25	19	-3	#
25	19	-13	H
25	21	13	G
25	21	3	#
25	21	-7	#
25	21	-17	H
25	23	19	G
25	23	9	#
25	23	-1	#
25	23	-11	#
25	23	-21	H
25	25	25	CG
25	25	15	C
25	25	5	C
25	25	-5	C
25	25	-15	C

25	25	-25	CH
30	18	-6	GH
30	20	0	G
30	20	-10	H
30	22	6	G
30	22	-4	#
30	22	-14	H
30	24	12	G
30	24	2	#
30	24	-8	#
30	24	-18	H
30	26	18	G
30	26	8	#
30	26	-2	#
30	26	-12	#
30	26	-22	H
30	28	24	G
30	28	14	#
30	28	4	#
30	28	-6	#
30	28	-16	#
30	28	-26	H
30	30	30	CG
30	30	20	C
30	30	10	C
30	30	0	C
30	30	-10	C
30	30	-20	C
30	30	-30	CH

So to conclude, our real scale universe ends at 100^30, or the present day, because since the big bang, only so much could have happened since this primordial expanding fireball. As of now, this is 13.8 billion years and counting. As an interesting take away note: Given that the origin of the whole universe is this past time horizon, frozen in time some 13.8 billion years ago, the toy scale universe is actually just our universe, viewed at a time right after the beginning. Its the fact that so much has happened since this initial moment, that makes the real scale universe such an interesting place to be in.

Chapter 2: The Three Pillars Of Fundamental Physics

This was the physics of the industrial revolution, written in 1687 by the greatest scientist who ever lived. Isaac Newton. However, by the turn of the 20th century, experiments began to show that Newtonian mechanics is not always right, and had to be modified to agree with these radically new groundbreaking experiments. There are three main sets of new phenomena, that were incorporated into the three pillars of modern science. The three pillars are special relativity, universal gravitation, and quantum mechanics. The fate of humanity rests on the unification of physical law.

***C*). Special Relativity:** The dimensions of space and time, arrange themselves such that the speed of light is the same, from all moving perspectives. This means that among many new phenomena, fast moving clocks run slow, fast moving rulers contract along their direction of motion, high speed motion breaks the simultaneous nature of time, and most importantly nothing moves faster than the speed of light. The fact that the speed of light moves at the same fixed speed no matter how its source is moving, means that the dimension of time rotates in an opposite way, than the three other dimensions of space rotate.

In the theory of Special Relativity, there is a Universal Constant. The constant of Relativity has a value of 2.99792458 * 10^8 m/s, in our system of units. We recognize this as the speed of light. This means that the speed of light is very fast. To get an idea on how fast this is, imagine a foot long segment of fiber optic cable. The latency of your internet connection would be a nanosecond. A nanosecond is a billionth of a second. Therefore, we can continue to say that, time runs at the same universal rate for both marbles. Despite the fact that these relativistic effects can be ignored in the everyday regime, we still live in a universe dictated by the physics of: special relativity. The fact that special relativity works at all, shows us just how weird our universe really is. Special Relativity was put together by Albert Einstein in 1905, in order to describe the strange behavior of the speed of light, along with four other papers that shake physics down to its foundations.

***G*). Universal Gravitation:** All particles attract all other particles, with an inverse square force field, in three dimensional space. This is why all objects fall to the ground at the same rate, why the planets move around the sun in ellipses with the sun at one focus and the other focus empty, and why a line drawn from the sun to a planet sweeps out equal areas in equal time intervals, and also explains why the semi major axis of a planet's orbit cubed is proportional to the orbital period squared, along with many other gravitational effects. It is the gravitational acceleration of space itself, sourced by a particle, that spreads out according to an inverse square law in 3D space. This is what keeps your feet on the ground, and the earth orbiting the sun.

In the theory of Universal Gravitation, there is a Universal Constant. The constant of Gravity has the value of 6.67408 / 10^14 m^3/g/s^2, in our system of units. This means that the strength of gravity is very weak. To get an idea on how weak gravity is, imagine two cars in deep space, each weighing a ton, parked right next to one another a yard apart. It will still take many hours for the two cars to stick together. Therefore, we can continue to say that, both marbles each maintain their motion, as they both independently travel in straight lines with a constant speed. Despite the fact that these gravitational effects can be ignored in the everyday regime, we still live in a universe dictated by the physics of: universal gravitation. The fact that universal gravitation works at all, shows us just how weird our universe really is. Universal Gravitation was discovered by Newton himself while trying to unify the motion of heaven and earth, and was published in his book, called the Mathematical Principles of Natural Philosophy.

H). Quantum Mechanics: Every wave can be thought of as a stream of particles. The total kinetic energy of such a particle is directly proportional to its corresponding probability wave frequency. Moreover, waves with shorter wavelengths correspond to identical particles with more momentum, that is to say, the product of mass and velocity. This leads to the notion that objects can be in more than two places at once, how particles and waves are actually the same thing, how these quantum waves have discrete harmonics like the specific notes on a musical intrument, and the weird notion that measuring one particle can reveal corelations in the properties of all other particles of the same type.

In the theory of Quantum Mechanics, there is a Universal Constant. The constant of Quantum has a value of 6.62607015 / 10^31 m^2*g/s, in our system of units. This means that the amount of quantum uncertainty is very certain. To get an idea of how certain quantum physics is, imagine a grain of dust, weighing less than a microgram, sitting on your desk at school. After 30 years, your kid, now sitting at your desk at school, notices that the same exact dust grain has moved by a millionth of an inch. Therefore, we can continue to say that, the two marbles both have definite positions as well as definite velocities. Despite the fact that these quantum effects can be ignored in the everyday regime, we still live in a universe dictated by the physics of: quantum mechanics. The fact that quantum mechanics works at all, shows us just how weird our universe really is. Quantum Mechanics was constructed by a band of nuclear physicists in order to explain the rainbow of a fluorescent light source.

To conclude, each of these pillars of physics, has radically altered our understanding of our two marbles. Our common sense vision of life as a mechanical linear progression, is just all wrong. Every pillar of physics, introduces a new universal constant. The associated physics reduces to our common sense, by making a series of approximations. So even though our common sense worldview works well in the everyday, in the grand scheme of things, our universe is stranger than fiction.

Chapter 3: The Unification of Physical Laws

Here we have the mathematics that unifies special relativity, universal gravitation, and quantum mechanics, for a single particle viewed from the origin. You are welcome to skip it, as the math involves derivatives and many high level math ideas. However, if you want to get a grasp on what the math says about each physics domain, or if like me, you are planning on building a physics game engine in python, then stick with me here.

I have the definitions of all the equations intact, so if you see something unusual, just rewind a bit to the earlier definition. Every equation should be defined as a partial differential equation involving a left hand side that involves the variables x, y, z for 3D space, t for time, and M for the particle mass. The right hand side is always zero for the defining equations.

Each equation describes the physics of a single point particle. So there is only one particle, the observer is identical to the particle, except that it is pinned down at rest to the origin for all times. Therefore one can say that all 8 equations answer the question, "If I were a particle, what would I look like, when seen from my very own outsider's perspective?". Since this is a physics problem, it is a perspective shift for understanding a single particle.

Each of the 8 equations, toggles the physics of C,G,H, binary wise. In the scale compressed universe, what I call a "toy scale" universe, I mentioned which physics applies at which scale. As we can see, each pillar of physics is either required or absent. This gives 2^3 unique domains, for a total of 8 defining equations.

To summarize each pillar of physics, we need to know why C,G,H are the pillars used and not some other. Remember the 3 limiting factors in the toy scale universe that define the boundaries of measurement scales. Each of these boundaries is actually a universal constant of physics. And because some scales are ruled out, and not others, means they have units. Here is a table that gives the pillar, the physics required for that pillar to be true, the constants I use in my equations, and the units of measurement for that constant as shown. Here is the table:

#:	**physics:**	**constant:**	**units:**
C	special relativity	1/c	s/m
G	universal gravitation	2*G	m*m*m/(g*s*s)
H	quantum mechanics	h/(2*pi)	m*m*g/s

Now for the fun part, as we are about to reveal what the 8 equations are. If you are scared of the complexity, don't worry, they might not make sense at first, but as soon as I explain them, you will get more familiar with them as we go. If it's too opaque, you are welcome to skip forward. Now here we go…

1). The Galilean transformed particle.

$$\frac{d^2[x,y,z]}{dt^2}=0$$

This equation says that the acceleration of the three position coordinates is zero. The acceleration is done by taking a second order time derivative of position. The brackets denote there are actually three equations as one. one for x, one for y, and one for z. The solutions are constant speed straight lines. Definite positions and velocities inside an absolute space and an absolute time. This was the defining equation for our two marbles in the beginning of this book.

C). The Lorentz transformed particle.

$$\frac{d^2 x^\mu}{\eta_{\mu\nu} dx^\mu dx^\nu}=0$$

This equation says the same thing, but within the Minkowski spacetime of special relativity. We have just replaced time with the full spacetime interval. And since time is now just another dimension, albeit a very weird one, we now have 4 equations instead of 3. They are still definitive, and still constant speed straight lines, but now for speeds approaching light speed, their percieved time slows down, effectively allowing travel into the far future, in as short of a personal time as one wants.

$$dx^\mu=[dt,dx,dy,dz]$$

This equation is the definition of a spacetime vector. It groups time t, with the spacial dimensions, x,y,z into a four dimensional vector, sometimes called a 4-vector. The greek "mu" is an index, not an exponent. Here, these indeces label, which spacetime dimension we are using for an equation. So equation mu equals t, gives the equation to be solved for time, the next for mu equals x, for the x equation. And so on, for all 4 equations. Its just a compact way of writing.

$$\eta_{\mu\nu} dx^\mu dx^\nu=-c^2 dt^2+dx^2+dy^2+dz^2$$

Lastly, and most important, is the spacetime interval. Notice the minus sign. That is crucial, for knowing that t is a time dimension. The reason: If the interval is zero, it must remain zero for all spacetime frames, the relativity principle, which means that is the reason for replacing the absolute time, with another absolute quantity. But we know the speed of light is absolute. Not time, not space, and definitely not angles. So the minus sign keeps the light speed constant, by making sure that time and space balance out to a constant value. In this case: zero.

G). The Kepler orbit problem.

$$\frac{d^2[x,y,z]}{dt^2}+\frac{GM[x,y,z]}{r^3}=0$$

This equation is non-relativistic, but introduces a new concept: gravity. We still have time as absolute, but now the path of our particle is no longer a straight line, and no longer maintains its motion through space. The particle is attracted to the origin, by

an acceleration that spreads out in 3D space from the origin. This is known as an inverse square law. This equation reproduces the eliptical orbits of a planet, or the hyperbolic orbits of a comet.

$$x^2+y^2+z^2=r^2$$

To make this work, we define the radius r, that tells you how far away the particle is from its origin. This is the simple pythagorean theorem in three dimensions. From it, orbit equation can be used in full.

CG). The Schwarzschild metric geodesics.

$$\frac{d^2x^\mu}{d\tau^2}+\Gamma^\mu_{\alpha\beta}\frac{dx^\alpha}{d\tau}\frac{dx^\beta}{d\tau}=0$$

This equation is the unification of special relativity and universal gravitation. Our particle travels along a path that is known as a geodesic. Geodesics are trajectories that minimize travel distance and maximize travel time in a curved spacetime geometry. The equation is presented in a compact form. So now lets unpack the symbols.

$$-c^2d\tau^2=g_{\mu\nu}dx^\mu dx^\nu$$

Like from special relativity, we have a spacetime interval. However instead of using the flat Minkowski spacetime, we use the curved Schwarzschild spacetime in cartesian-Eddington coordinates. This means that the distances and elapsed times are exactly perturbed away from the flat spacetime case.

$$H=\frac{2GM}{c^2r}$$

Here is the gravitational potential, written in dimensionless units. It is the magnitude of the pertubation and is the sole reason for gravitational time dilation, even at rest where in special relativity time flows as usual. It is this discrepancy in the flow of time that causes gravity in the first place.

$$l_\mu dx^\mu=c\,dt+\frac{(x\,dx+y\,dy+z\,dz)}{r}$$

Alongside the magnitude, we have a direction. This direction points inward at the speed of light. In fact, it tells us that the gravitational field only responds at the speed of light. That is a hallmark of all theories that obey special relativity. The farther away the particle is, the more time it takes for the light-speed influence to relay information to us. We call this the lookback time, or retarded time. In other-words, we can think of this vector as the flow of gravitational information into the origin.

$$g_{\mu\nu}=\eta_{\mu\nu}+H\,l_\mu l_\nu$$

Putting it together, we arrive at the full spacetime interval. We recall the Minkowski metric from earlier. Like with the Minkowski spacetime, the metric tensor is a 4 by 4 matrix, but now we are adding an exact gravitational perturbation that gives us the schwarzschild metric. The two spacetime indeces tell us the metric tensor is a matrix.

$$g^{\mu\nu}=\eta^{\mu\nu}-H\,l^\mu l^\nu$$

This matrix has an inverse. Useful for computing the forces in spacetime due to parallel transport, we can see that the inverse is simply a sign flip of the potential, and a reversal of time for the lookback time vector. Everything works here too, thanks to the linear nature of the cartesian coordinates.

$$\partial_\mu = \frac{d}{dx^\mu}$$

We define partial derivatives as follows. It is simply the rate of change in time for the time component, and the gradient operator for the spacial components. This allows one to take derivatives of the metric tensor to find the christoffel symbols, this is very similar to how one finds the force by taking the gradient of the newtonian potential. We do exactly that in the following equation:

$$\Gamma^\lambda_{\mu\nu} = \frac{1}{2} g^{\lambda\rho}\left(\partial_\nu g_{\rho\mu} + \partial_\mu g_{\rho\nu} - \partial_\rho g_{\mu\nu}\right)$$

Here are the christoffel symbols. It is a 4 by 4 by 4 tensor. So 64 numbers to deal with. It is defined in such a way to cancel the local curvature generated by the metric, and can be used to parallel transport any vector along a curve. The geodesic equation does exactly that for the spacetime velocity 4-vector. So you can thus think of this as the definition of how spacetime accelerates in any direction along any path. It is the relativistic version of a force vector.

H). The Shrodinger wave equation.

$$i\hbar \frac{d\Psi}{dt} + \hbar^2 \frac{\Delta^2 \Psi}{2M} = 0$$

This equation is the quantum version of a galilean transformed particle. Also known as the schrodinger equation, it tells us how the wavefunction PSI evolves over time. This means that we can only know the probability of finding our free particle. The probability is calculated by overlapping initial and final wavefunctions. Such as where the particle is for the initial wavefunction, and the final wavefunction for where you are looking for it.

$$\Delta^2 = \frac{d^2}{dx^2} + \frac{d^2}{dy^2} + \frac{d^2}{dz^2}$$

Here is an important operator known as the Laplacian. It is the pythagorean theorem in 3D for the gradient operator, like how the radius is the theorem applied to the position. Therefore, one can think of this scalar operator as the square of the vector gradient operator.

$$i^2 = -1$$

Also important here is a new definition for the imaginary unit, which squares to negative one. Very important for describing changes of phase in the wavefunction. For probability to be conserved for a simple plane wave solution, one has to have a constant probability amplitude, which is impossible for real valued equations, that is why the unit

is useful, to have the phase rotate over time in the complex valued solution to the equation.

CH). The Klein Gordon equation.

$$\left(\eta^{\mu\nu}\partial_\mu\partial_\nu-\frac{M^2c^2}{\hbar^2}\right)\Psi=0$$

This equation unifies special relativity with quantum mechanics. The Klein Gordon equation is the relativistic generalization of the shrodinger equation. It extends to relativity, by using the flat Minkowski metric. The solutions are plane waves like the shrodinger case, but this time being compatible with relativity, they travel at any speed, even close to light speed.

GH). The Hydrogen atom wavefunctions.

$$i\hbar\frac{d\Psi}{dt}+\hbar^2\frac{\Delta^2\Psi}{2M}+\frac{GM^2}{r}\Psi=0$$

For something quite new, we unify universal gravitation with quantum mechanics. Even without special relativity, it is amazing that the solutions for a single particle coorespond to the atomic orbitals of the periodic table for chemistry. This occurs because like for electromagnetism, which dominates the atom's electrons, gravity as we already know also spreads out into space. It is the quantum version of Kepler's orbits.

CGH). The Klein Gordon equation in the Schwarzschild metric.

$$\partial_\nu\left(g^{\mu\nu}\partial_\mu\Psi\right)-\frac{M^2c^2}{\hbar^2}\Psi=0$$

And finally, we get to the apex equation. The equation that unifies all three pillars of physics into one: Special relativity, universal gravitation, quantum mechanics. All into a single equation. It's the Klein Gordon equation, but for the curved spacetime of the Schwarzschild metric. It can also be looked at as the relativistic generalization of the hydrogen atom wavefunctions. Here the solutions are found by some analytical functions like confluent Heun functions, a type of hypergeometric function, along with the spherical harmonics from before. This is what a particle is in all domains, even when the physics becomes irrelevant to use.

Chapter 4: The Black Hole Particle Duality

Did you know that all particles such as electrons of electricity, photons of light, even quarks, are all rotating black holes. A black hole is a region of space in which gravity is so strong that light cannot escape it's deadly grip. A black hole that spins like a top on the table is known as a rotating black hole. The only difference between a black hole and a particle is size. Heavy particles act more like black holes, and light black holes act more like particles, because they are the same mathematical object.

All fundamental particles are black holes and all black holes are fundamental particles. They both share the exact same mass and spin. They also both live in the cartesian Kerr-Schild coordinate system that allows the separation of the gravitational field from the Minkowski background spacetime. The geometry is given by the Kerr solution of vacuum General Relativity, which describes a rotating black hole. Electric and other charges are set to zero, as they do not exist as sources. The duality only applies to mass and spin, both of which are particle labels and black hole labels, strictly because the Poincare Gauge Theory has the same local symmetries of Minkowski spacetime, yet also reduces to vacuum General Relativity, when all sources are removed completely.

Rotating Black Holes are Particles

To unify special relativity with universal gravitation, imagine two gravitating marbles. Placed at rest an infinite distance apart, the two marbles will gradually begin to accelerate toward one another. The speed needed to break the fall, is known as the escape velocity, and is also the speed at which space itself carries the marbles together. However, we know that gravity spreads out with distance, meaning that the escape velocity would exceed light speed at a close enough distance. In a sense, space itself is falling inwards, faster than light can. And since nothing can propagate faster than light, everything inside this distance is trapped forever. This is the event horizon of a black hole!

Going back to our two marbles, we know that they are actually two black holes. The mass of each black hole, is simply the size of its own event horizon. The year is 1915. Albert Einstein completes his General Theory of Relativity. Weeks later, Carl Schwarzschild found the spacetime geometry around a simple black hole. The Schwarzschild spacetime reduces to special relativity and universal gravitation, in their respective domains. However, black hole orbits do things not seen before in science. Time slows down, light bends, orbits precess around. Closer in, gravity increases like a rip tide, rendering circular orbits unstable. Even closer, and it is possible for light to orbit temporarily. Crazy stuff.

For fun, lets dive into a Schwarzschild black hole. Far away from the hole, its gravity seems normal, since the paths of objects around it, the orbits, behave as we would expect. The slowest orbits are the elliptical orbits, like the earth around the sun

for example. Faster orbits, like that of a comet passing by a planet, are known as fly-by orbits. The fastest orbits are the straight lines that light takes to reach your eyes. Closer in, say within a few dozen black hole radii away, the gravity is so powerful that light rays will noticeably bend, just like the flyby orbits we mentioned. On the other hand, the slower elliptical orbits are also acting very strangely. They undergo a phenomenon known as precession, which is to say that the closest point of the orbit, the perihelion, shifts in the same direction of the orbit itself, turning a simple ellipse into a daisy pattern. Then, at three black hole radii from the black hole, circular orbits become unstable. This means that a small push will either send us flying into the hole, or off into deep space. At this distance, orbits zoom and whirl around the hole. The orbital precession and time dilation effects are clearly noticeable. Closer in than three radii from the hole, faster and faster elliptical orbits become unstable, until we arrive at two black hole radii from the black hole, at which flyby orbits start being unstable too. The only orbits possible are the highly bent light rays, which also follow flyby orbits. Then, at a special distance of one and a half radii away from the black hole, light can orbit the black hole. However this orbit is unstable, and the light rays either fly off to infinity, or plunge into the black hole. Even closer than this, and orbits do not exist, since the orbital speed needed would be faster than light. Just above the event horizon, it is still possible to escape the gravity of the black hole. However, as we approach the horizon at one black hole radius, the chance to fly away gets slimmer and slimmer. Time slows to a halt, when seen from the outside. Then as you cross the invisible spherical boundary, you are doomed to hit the central singularity, where everything you know comes to an end. Seen from outside however, nobody even sees you cross the event horizon at all, as your image fades away on the black hole surface.

In 1964, Roy Kerr found another solution to Einstein's Theory, one that extends the Schwarzschild solution to include a new phenomenon, spin! In effect, spacetime gets dragged along with the rotation, causing even more mayhem to our orbital path around the hole. This is known as frame dragging. There are an inner and outer event horizon, and even an inner and outer ergo sphere, within which it is possible to extract rotational energy. Moreover, a rotating black hole, spinning as fast as possible, has unstable orbits all the way out to nine black hole radii out going against the spin, yet can have stable circular orbits traveling along with the spin of the black hole, all the way down to the outer event horizon itself. Even so, the Kerr spacetime, reduces to the Schwarzschild spacetime, for a black hole that does not spin. The spin of the black hole, is what causes this so called frame dragging. As an example, the orbit of the earth around the sun, is a near circular ellipse. The constellations of the zodiac, are the stars on the far side of the earths orbit during that month. The path of the earths orbit traces a two dimensional plane, known as the ecliptic plane. For our rotating black hole scenario, this is no longer the case, as any non equatorial orbit about the black hole, tilts. That is to

say that the ecliptic plane of our orbit is shifting like that of a spinning top on the table. This is even more wild than anyone could ever imagine!

Now imagine we have a handful of rotating black holes, all orbiting through a common spacetime, with their own masses and spins. Black holes spiral inwards towards one another and merge, releasing gravitational waves. These tremors in spacetime, then bend around other nearby black holes, which are merging themselves. Its just a gigantic mess of curved geometries. After a while, everything settles down to a few large black holes, with higher masses and new spins, all moving away from one another. In the theory of general relativity, matter tells spacetime how to curve, yet spacetime tells matter how to move. The matter we are referring to are the black holes themselves. Note that it is not just space or time itself that is bending, but our full spacetime geometry. This is the worldview we get, after unifying special relativity with universal gravitation.

Quantum Matter Waves are Particles

To unify special relativity with quantum mechanics however, imagine two quantum marbles. You roughly know their distance and relative velocity after measuring them. Lets say we want to measure the separation between the two marbles, this time with a much greater precision. The uncertainty in the relative velocity of the marbles will have increased by a similar factor. By measuring the distance precisely enough, the uncertainty in relative velocity will exceed light speed. When this happens, you have discovered antimatter!

Going back to our two marbles, we know that they are actually two quantum waves. The mass of each quantum wave, is simply its own frequency. The year is 1925. Erwin Schrodinger finds a relativistic wave equation for these quantum waves. Weeks later, Klein and Gordon rediscover this relativistic wave equation, after Schrodinger abandoned it. These Klein Gordon waves reduce to special relativity and quantum mechanics, in their respective domains. However, Klein Gordon waves do things not seen before in science.

Just for fun, lets take a closer look at these Klein Gordon waves. Like all waves, Klein Gordon waves can be decomposed into a series of plane waves with definite frequencies and wavelengths. Take one of these plane waves for example. It is called a plane wave for a reason. Simply because as the wave scrolls through space, it has wave fronts that are flat two dimensional surfaces, or planes. The perpendicular distance between the parallel wavefront planes, is the wavelength. The frequency is just the number of cycles per second. So in other words, a plane wave is the building block of any wave. Lets now boost to a moving perspective, such that we are moving with the wave. At this point, the wavelength is so long, that for our purposes, the plane wave is now a synchronized sine wave. Its like the tides going in and out of the shore, as the whole flat ocean seems to rise and fall every day, in perfect unison. As we boost to a slowly moving perspective, the frequency has increased very slightly, however the synchronized wave

is now out of sync again, as another plane wave, with a very long wavelength. At such slow speeds, the frequency of the waves is fairly constant, and could be ignored. The remaining phase angle of our wave, now has a much lower frequency, now in proportion to the kinetic energy of its associated quantum marble. The inverse wavelength of our nearly synchronized plane wave on the other hand corresponds to the linear momentum of our marble. As we boost away with faster and faster velocities, the wavelengths of our plane wave get shorter and shorter, and the frequency increase becomes noticeable. As we boost much faster, ever closer to light speed, the plane wave now has a very high frequency and a very short wavelength, such that the plane wave now seems to travel at exactly the speed of light. Boosting more will only make the waves even shorter, as they continue to travel at exactly the speed of light.

In 1928, Paul Dirac found another relativistic wave equation, one that extends the Klein Gordon equation, to include a new phenomenon, spin! The spin of the Dirac waves, is due to a new direction that these waves can vibrate in. In some sense, the more ways in which these quantum waves can vibrate, the greater the spin. Spin can only increase or decrease by half steps. In this case, we have a spin up and spin down electron, along with a spin up and spin down positron. Each and every component, are themselves Klein Gordon waves. It is only when we change our point of view, that the components mix into one another. For example, take a Klein Gordon plane wave vibrating purely as a spin up electron. If we rotate this wave, and look at it from another angle, the plane wave, with everything else being the same, is now vibrating as a spin down electron. Similarly, if we boost our whole setup so far, the vibration in the first two matter electron components, is now slightly vibrating the last two antimatter electron components also, also known as the spin up and down positrons. We say that Klein Gordon waves and Dirac waves, have the spin that they have based on this simple idea. Klein Gordon waves have a spin of zero, because if we rotate the setup by any angle, even after many turns, everything stays the same. This is obvious. However, if we rotate a Dirac wave by a full turn, the components mix only half of what we expect. This means that it takes two full turns of a Dirac wave to return to its initial configuration. We say that a Dirac wave has a spin of a half, for this very reason.

Now imagine we have a bunch of Klein Gordon and Dirac waves, all undulating independently throughout spacetime. Every quantum wave, vibrates in its own abstract dimension, with every dimension corresponding to the probability coordinates of every marble. This is similar to how the spin of all these marbles acts like. The Klein Gordon waves, overlap and build up, whereas the Dirac waves interfere and sometimes cancel out. In this theory, it is all about a new entity called a relativistic quantum field. Imagine a crystal array of quantum marbles that extends out to infinity in all directions. If we hit this crystal with a hammer, it will vibrate just like a big block of rubber. As it turns out, these vibrations are completely identical to our Klein Gordon and Dirac waves. Since these vibrations are nothing but sound waves living in a crystal lattice made of quantum

balls and quantum springs, there should be a minimum unit, or quantum of a field. As luck would have it, every field quantum acts independently, just like a marble. Therefore our system of a bunch of Klein Gordon and Dirac waves, is thus nothing more than a collection of field quanta. This is our worldview after unifying special relativity with quantum mechanics.

Why Particles have both Mass and Spin

Our two worldviews, one of the heavy, and the other of the light, both share some common features. Black holes and quantum waves, both have mass, and also both have spin. Because of this fact, a setup of the exact same physical system in one worldview, will mimic the behavior in the other worldview. It turns out that the atoms and subatomic particles, of which we are made, are not marbles at all. They are instead a kind of quantum black hole. A quantum black hole, behaves more like an actual black hole if it is really heavy, yet also acts like a quantum wave if it is really light. Therefore, in order to understand this, we needed to unify the three pillars of physics into a single framework. This means that everything is one. Literally!

At this point, we have all of the pillars of physics we need, in order to unify all of physics into the theory of everything. However, such a unification of physics will require two radical paradigm shifts. The first idea is all about special relativity, and how to unify it with the rest of physics. The second idea is to reconsider the properties of matter, such as mass and spin. Lets review some key ideas in special relativity before we move on. The spacetime of special relativity, also known as Minkowski spacetime, replaces the idea of absolute time, with the idea of an absolute light speed. With this idea in mind, the symmetries of space and time, unify into a structure known as spacetime.

The spacetime of special relativity, called Minkowski spacetime, has certain symmetries, known as Lorentz Transformations. They keep the speed of light constant, under a change in perspective: The relativity principle. They are the symmetries of spacetime itself: 3 Hyperbolic Boosts, 3 Spacial Rotations, 4 Spacetime Translations. From these symmetries, emerges new phenomena.

In quantum field theories that involve relativistic wave equations, which live on Minkowski spacetime, the mass and spin of these field equations, are a direct result of spacetime symmetries. Mass is the minimum frequency for a wavepacket at rest. Spin is the amount of change between field polarizations under a change in spacetime perspective. Due to the quantum principle, the mass and spin of a wavepacket, when zoomed far enough away, appears to act like a spinning top, with the mass being the top's inertia, or resistance to changes in motion, and its spin being its angular momentum while spinning.

However, all relativistic wave equations, still live on flat Minkowski spacetime. Sure, there could be interactions between fields that give rise to non-gravitational forces. This is what the standard model does, as it is a quantum field theory, that maps

out the possible interactions between wavepackets. However, in Einstein's General Theory of Relativity, gravity is the result of the curvature of spacetime itself. Therefore in General Relativity, spacetime is a classical field theory in its own right. The reasoning to this approach is astonishing, because one has to invent a new way to produce classical field theories involving symmetries.

The answer is a new kind of symmetry known as local symmetry. So far, relativistic wave equations had global spacetime symmetries: Mass and Spin. However local symmetries are symmetric only in small regions of the field spaces. We already encountered local symmetries in the standard model. They were not local spacetime symmetries, but local field symmetries. However, one might ask what happens when one makes spacetime symmetries local in their own right. The answer: General Relativity!

Okay not quite, as I must admit. Although General Relativity is a classical field theory, where spacetime curvature gives rise to gravity. It doesn't have all of the local symmetries of spacetime. Only spacetime translations become local symmetries in Einstein's theory. However, what we are asking is what happens when all spacetime symmetries become local symmetries. In the general case scenario, one must intoduce a new concept known as torsion… Just like energy density currents and momentum density currents couple to gravity, spin densities couple to torsion. And, just like how the curvature of spacetime is the definition of gravity, torsion has to be included to make sure the boost and rotation symmetries are also local in nature. The result is a new theory called: Poincare gauge theory, or gauge theory gravity, which has field equations known as the Einstein Cartan Theory.

However, in our theory, we are not to couple the fields of the standard model to the einstein cartan theory. And here's why? Solutions of the einstein cartan theory produce black holes, whether or not we couple other fields to the theory. I mean why not let everything be fields, including spacetime curvature and torsion, and what is the deal with black holes? This is a bug, not a feature. Black holes have to be associated with point particles… And as we know, point particles do not exist. At least in classical field theory. But, in this oberservation comes a truly surprising result.

As we know we applied quantum physics to a single point particle, and recovered a classical field theory of relativistic wave equations. The massive Klein Gordon and massive Dirac equations respectively. Therefore, if black holes are also points, means one thing: Every rotating black hole with a given mass and spin, must be associated with a relativistic wave equation that describes a single quantum particle! And, in our einstein cartan theory, which we just coupled it to the standard model field theory, and that doesn't do it justice. Black holes exist regardless of field content. What we need is a theory where black holes exist, only when the fields are vibrating, and when no fields are vibrating, there shoudn't be any black holes present. Moreover their mass and spin should also be completely identical. How to do this?

Since Minkowski spacetime has the same global symmetries, even in the case with the Einstein Cartan theory, there shoudn't be any extra local symmetries. By coupling the standard model to it, we included plenty more extra symmetries that the Einstein Cartan theory couldn't handle. Let me say it backwards: All local symmetries have to have global symmetry counterparts. And in the standard model, we only have a global spacetime symmetry, there are no global field symmetries. Therefore, lets keep the standard model and the Einstein Cartan theory separate, for now.

Thus, in the vacuum, the Einstein Cartan theory, reduces back to good old General Relativity. How? Without any mass or spin present from other field theories, the right hand side of the Einstein Cartan theory vanishes. Spin vanishes, and so does the mass. Torsion is algebraic, so it completely vanishes without spin, leaving us with general relativity. But in general relativity, the energy momentum tensor is also all zero, due to vanishing mass. Therefore, one is left with general relativity without any sources.

In vacuum general relativity, there are plenty of solutions. One can consult a numerical relativity simulation, just to be sure… rotating black holes orbit and collide, gravitational waves propagate around everywhere. And, everything is just vacuum. So clearly, one has sources without a source, particles from vacuum, or otherwise put: Everything from nothing!

What we need now, is a way to directly couple these rotating black hole solutions, to our relativistic quantum particles. We need a way to produce the spacetime geometry straight from its solutions, and not the other way around.

The Cartesian Kerr-Schild Spacetime Geometry

Enter the cartesian Kerr Schild spacetime geometry! In laymans terms, it is the spacetime geometry for a rotating black hole in orthogonal light cone coordinates. They have some nice properties, such as being exactly linear solutions to vacuum general relativity. They have constant metric determinant, are lorentz transformed solutions of one another, and in these coordinates, the vacuum einstein's equations, becomes a simple tensor relativistic wave equation. Everything is exactly linear! No gravitons, no renormalization, no issues, just solutions that coorespond to point particles. And since, these solutions are the result of an exactly linear coordinate system, tells us that the superposition principle still holds. Therefore, one can reconstruct the entire spacetime geometry in the Kerr-Schild form.

What is needed now, is to propagate the standard model as a quantum field theory over this curved background geometry. We introduce covariant derivatives for all fields. However for the matter fields which use Dirac spinors, there is a sublety, which needs to be addressed: We need the spacetime frame instead of the metric tensor. Luckily Kerr himself, used the so called tetrad approach to produce his spacetime geometry for a rotating black hole. In some research articles, it has been reproduced in cartesian

Kerr-Schild coordinates. Using a set of light cone adapted null geodesics, one can produce the correct tetrad frame field.

It is the cartesian Kerr-Schild spacetime geometry, that allows one to treat black holes as particles. Traditionally, one uses curved coordinates of spacetime itself. Spacetime becomes the gravitational field, and the equations become hard to solve, precisely because gravity sources gravity. Since one uses curved coordinates to start with, it is not to obvious to tell which are more useful than other coordinates.

As it turns out, the cartesian Kerr-Schild coordinates are uniquely special, in that they separate the gravitational field from the spacetime background. What's more amazing is that this spacetime background is the Minkowski spacetime from special relativity, which means that the gravitational field evolves as a non interacting, massless, spin 2, relativistic wave equation. We can now apply many new ideas from electromagnetism to gravity, like the retarded potentials, null hypersurfaces, and so on, and yet, also be able to understand why it was the coordinate choice, not the linearity, that explains why general relativity is so highly nonlinear.

The main culprit to why gravity becomes self interacting, is a non kerr-schild coordinate choice. Think of it, if one chose spherical coordinates in say the maxwell's equations of electromagnetic theory, one would need to use much of general relativity anyways to write this spin 1 wave equation in these annoying coordinates. The same thing applies to the Kerr-Schild gauge.

In this coordinate system, gravity is a spin 2 field equation, and like electromagnetism, which is spin 1, changing coordinates results in non linear couplings. In fact this is why self interactions seem to turn off in this coordinate system. Even more amazing than this, is that the inertial frames in spacetime become globally invariant to Lorentz transformations, just like in special relativity.

In general relativity, it only works per point, or locally. By using full blown General Relativity, one looses this important distiction, and the curved spacetime background causes confusion. In a sense, general relativity, only actually becomes necessary for curved backgrounds, as we saw for Maxwell's equations in a spherical background. However by extracting out the Kerr-Schild form, one can indeed show that the gravitational field and the spacetime background are indeed separate.

Chapter 5: The Mathematical Formulation of a Particle

We know that rotating black holes are particles. We know that quantum matter waves are particles. We know that particles are characterized only by their mass and by their intrinsic spin. By putting these ideas together, we first know that a rotating black hole is by definition a quantum matter wave and vice-versa. In the last mathematical details section, we unified special relativity, universal gravitation, and quantum mechanics, all for a single particle with mass M. The last equation was the full CGH equation: The massive klein gordon equation in the schwarzschild spacetime geometry with any identical mass. We now know how to introduce spin correctly for both the GC and HC counterparts.

In this mathematical details section, we build upon the CGH equation for a spinless particle, by including spin. Like mass, the spin of the black hole and the spin of the wavefunction must be the same. But unlike mass, which can take on any positive value, spin is defined to be spin half, like that of an electron, for both the black hole and the wavefunction. It is the full CGH equation with spin half that we are after, and it will require much more technical machinery than we had for the spin zero case. Here comes the following equations.

The Symmetries of Minkowski Spacetime

$$\Lambda = expm\begin{pmatrix} 0 & K_x & K_y & K_z \\ K_x & 0 & -J_z & J_y \\ K_y & J_z & 0 & -J_x \\ K_z & -J_y & J_x & 0 \end{pmatrix}$$

This equation is the definition for the Lorentz transformations. As you can see, boosts are symmetric, but rotations are anti-symmetric. This ultimately stems from the fact that the time dimension rotates in an opposite way than the three spacial dimensions rotate. This in turn happens because all of the Lorentz transformations keep the full Minkowski spacetime interval the same between spacetime frames.

$$\Lambda^{-1}\eta\Lambda = \eta$$

Here is the reason for the invariance. And it's not just light-speed that travels at the exact same speed, but the full spacetime interval. We can clearly see that the Lorentz transforms themselves form a kind of inertial spacetime frame. Having all spacetime frames related by Lorentz transforms, means that spacetime intervals in each frame will produce the same answer across frames. This will be important for later when we derive the tetrad which is a type of spacetime frame used for a curved spacetime geometry.

$$\eta = \begin{matrix} -c^2 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{matrix}$$

Here is the Minkowski metric tensor. If one applied spacetime 4-vectors to it, we would arrive at the flat spacetime interval. But here, we have the bare bones 4 by 4 matrix version. Clearly, time rotates differently, because it squares to a negative distance. Time is an imaginary dimension.

GC with spin: The Kerr Spacetime in the cartesian Kerr-Schild Geometry

$$a = \frac{\hbar}{2Mc}$$

In the spin half case, both the Kerr black hole and the Dirac matter waves have to have the same spin. For the dirac equation, it is naturally spin half. However the geometry of the Kerr spacetime, which describes black holes with intrinsic spin, the spin can take on any value. Here, we just fix it to be spin half, and then fix it into dimensions of distance.

$$\frac{x^2+y^2}{r^2+a^2}+\frac{z^2}{r^2}=1$$

This equation is a new definition for the radius, which also depends on the spin parameter "a". The lookback time then becomes the usual definition of the radius function divided by the speed of light. This is only natural in oblate spherical coordinates, and will be used in the following formulas.

$$H=\frac{2GMr^3}{c^2\left(r^4+a^2z^2\right)}$$

Remember the gravitational potential from earlier. Here is the same thing, but with spin included. Sometimes called the Appell potential for the electric potential field around a loop of wire, the same applies to gravity. Since in cartesian coordinates, the point particle singularity is an extended ring, sometimes called a ringularity. The gravitational potential around such an extended ring is what this equation defines.

$$l_\mu dx^\mu = c\,dt+\frac{r\left(x\,dx+y\,dy\right)}{r^2+a^2}+\frac{a\left(y\,dx-x\,dy\right)}{r^2+a^2}+\frac{z}{r}dz$$

Like before, alongside the gravitational scalar potential, is the gravitational vector potential. It tells us the paths of light-rays that are directed straight down towards the singularity. However as we know, the spin of the hole, creates a frame dragging effect, that spins the paths off the past light cone. Nonetheless, the vector potential still traverses the lookback time down to the ringularity. If we had a camera at the ringularity, every point on the celestial sphere, would be an oblate spherical projection, and the vector potential will just be a incoming light ray at that specific angle.

HC with spin: The Dirac Equation and other Relativistic Wave Equations

$$\hat{O}_{\alpha\beta}=\left(\gamma^{\mu}D_{\mu}-i\frac{Mc}{\hbar}\right)_{\alpha\beta}$$

Now we get to the quantum matter waves. This equation is the definition for the Dirac operator. Like the Klein Gordon operator, the Dirac operator is a kind of square root of the Klein Gordon operator. The alpha and beta indeces are not space-time vector indeces but a more abstract spin space, sometimes called polarization space. If one took this operator and squared it, the cross terms would cancel out, leaving the gamma matrices that will anticommute to give the Minkowski metric, recovering the Klein Gordon operator.

$$\hat{O}_{\alpha\beta}\Psi_{\beta}=0$$

Here is the full Dirac equation. The wavefunction PSI, has its usual definition, as overlapping two wavefunctions, one initial, and one final, to give a total probability of such a transition to occur. As one might see with the polarization label beta, that it's actually 4 seperate equations side by side. Its the way the cross-terms interact between the equations that is the reason for its structure obeying special relativity.

$$\gamma^{\mu}=[\hat{t},\hat{x},\hat{y},\hat{z}]$$

This is where the magic happens. This is the gamma vector. The index "mu", is now an actual spacetime 4-vector. But each term is not just a number, but a 4 by 4 matrix in polarization space. Think of it like the definition of what t,x,y,z, all are without knowing what the Minkowski metric is. By multiplying together different gamma matrices, we get new gamma matrices that depend on which two matrices you multiplied and in which order. We can say that the gamma matrices are the square root of the Minkowski metric.

$$i=\hat{t}\,\hat{x}\,\hat{y}\,\hat{z}$$

Now, because we have 4 by 4 matrices of spacetime itself, using the imaginary unit by itself will add unecessary complexity of using complex numbers, which would introduce electric charges, which don't exist here, because charges don't input into the Einstein-Cartan theory. Instead we redefine the imaginary unit as another gamma matrix, sometimes called the 4-volume element or fifth gamma, as it handles integration in spacetime algebra.

$$\hat{t}=\begin{matrix}0 & 0 & 0 & -1\\ 0 & 0 & 1 & 0\\ 0 & -1 & 0 & 0\\ 1 & 0 & 0 & 0\end{matrix}$$

This is the 4 by 4 matrix definition for the t direction. As we can see it only has real valued components. This matrix points into the direct future.

$$\hat{x}=\begin{matrix}1 & 0 & 0 & 0\\ 0 & -1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & -1\end{matrix}$$

This is the 4 by 4 matrix definition for the x direction. Being real valued, it points to the right.

$$\hat{y}=\begin{matrix}0&0&0&1\\0&0&-1&0\\0&-1&0&0\\1&0&0&0\end{matrix}$$

This is the 4 by 4 matrix definition for the y direction. Being real valued, it points to the front.

$$\hat{z}=\begin{matrix}0&-1&0&0\\-1&0&0&0\\0&0&0&-1\\0&0&-1&0\end{matrix}$$

This is the 4 by 4 matrix definition for the z direction. Being real valued, it points to the top.

CGH physics for a particle with spin

$$e^{\mu}_{A}=\Lambda^{\mu}_{A}+\frac{H}{2}\left(\Lambda^{\mu}_{B}\eta^{CB}l_{C}\right)l_{A}$$

This equation is defines the tetrad, which is a field of inertial spacetime frames. It is the most important equation for the whole book. The reason isn't just that tetrads allow for coupling to fermionic fields, but that this tetrad is the only tetrad that is both globally Lorentz covariant, and resides in the cartesian Kerr-Schild coordinate system. This form is what is required to turn a singularity for a rotating black hole from a pathology that cannot be renormalized away, into a simple trajectory of a particle.

$$e_{\nu A}=e^{\mu}_{A}g_{\mu\nu}$$

Since the tetrad converts between flat and curved inertial frames, we need an inverse tetrad. This can be achieved by multiplying it by the metric tensor we defined earlier in the book, but using the new definitions for the radius, potential, and vectors.

$$e^{\nu}_{A}=e_{\mu A}g^{\mu\nu}$$

We can also undo this operation, now by multiplying again not by the usual kerr metric, but with the inverse kerr metric.

$$\omega_{\mu AB}=e_{\nu A}\Gamma^{\nu}_{\sigma\mu}e^{\sigma}_{B}+e_{\nu A}\partial_{\mu}e^{\nu}_{B}$$

This equation right here, is the spin-connection. It uses the Christoffel symbols for parallel transport, and computes an analogous kind of parallel transport for polarization space tensors.

$$\gamma^{A}=[\hat{t},\hat{x},\hat{y},\hat{z}]$$

Here we redefine what the flat spacetime gamma matrices are. A and B are the flat spacetime 4-vector indeces, whereas mu, nu, sigma, etc, are for the curved spacetime 4-vector indeces. With this, we still have to go back and redefine the curved gammas.

$$\Sigma^{AB}=\frac{1}{4}\left(\gamma^{A}\gamma^{B}-\gamma^{B}\gamma^{A}\right)$$

As the gammas anti-commute into the metric tensor, they commute into something else, the sigma tensor. It also lives in polarization space as the gammas do.

$\Gamma_\mu = \omega_{\mu AB} \Sigma^{AB}$

We define the exact perturbation that the Kerr tetrad has on the flat spacetime gammas. Since interactions can cross-link terms, the spin-connection tells us how much a given cross-linking between gammas will happen.

$D_\mu = \partial_\mu - \Gamma_\mu$

Remember the force equation for the geodesic equation. This is the force equation for the Dirac equation. Since we are using the spacetime gradient 4-vector, we can generalize it to include such forces. This is called a covariant derivative operator.

$\gamma^\mu = e^\mu_A \gamma^A$

Lastly, we have to bring the flat gammas into curved spacetime, see the change from A to mu. We can do this my multiplying the gamma matrices by our Kerr tetrad. This completes the equations we need to simulate a single CGH particle observed from its own origin, with spin included.

Chapter 6: Fields are Fundamental

So far, the discussion has centered around particles, specifically what a particle is in various domains of physics. First we touched upon topics like units of measurement, dimensional analysis, and scale compression, in order to show how and why seemingly incompatible theories are actually describing the exact same thing at different domains of scale. We learned that special relativity, universal gravitation, and quantum mechanics, are the three pillars of physics, and by unifying these three pillars will reveal what our ultimate formula must encapulate. Next, with the mathematics included, we unified a single particle in all 8 domains of physics. We showed where the physics of general relativity becomes baroque in its complexity, why mass and spin are both fundamental in all domains, and introduced the new coordinates that seperate the background of special relativity, from its gravitational field. Then we completed our discussion of particles with a unified equation for a spin half particle, that now stands side by side with our unified equation from earlier for a spinless particle, that unified the three pillars. It's these two equations that are the foundation for a universe made of particles.

We have been talking about particles, as if they actually exist. Particles don't exist, but fields do exist! The link between the fields that exist and the particles that define our mathematics is an interesting one to find out. In this section, I will try to convince you, the reader, exactly that… That particles are just an illusion, created from fields. Before we begin, we need to rethink why we even mentioned particles earlier in the book. If they don't exist fundamentally, then why did we bother with all of this? Why did I put you through the ideas we mentioned so far?

The answer is that even though particles are not fundamental, and fields are indeed rock-bottom central to the existence of the universe, particles emerge out from the fields. So even though they are not what exists fundamentally, particles do appear to exist, and do so in a multitude of ways. We will soon see that although fields are what is reality, the particles that emerge from them actually follow the exact same equations we already wrote down.

If particles can emerge from fields, and do so in a variety of ways, how do we know which perpsective on what a particle is is the right one? How can it be that a particle is simultaniously: a rotating black hole in vacuum general relativity, is also a quantum mechanical harmonic of a field equation vibrations, and yet also be a quantum mechanical version of multiple identical trajectories that follows the same equations as its field version. Understanding how a particle emerges from a field theory is the main topic of this section, and moreover it is the realization that all of these ways of describing particles are describing the same exact particle. It's clearly the case that the way we describe them is a matter of perspective, because there is no underlying reason why we should interpret a particle in any way more important than any other way.

Its the same particle! Therefore we should treat these methods are only tools to get particles, and it is this fact that demotes particles from being fundamental.

The True Spacetime Field Equations

Since fields are the ontology, lets go through our first example of particles emerging from fields. In standard textbook general relativity, spacetime and the gravitational field are the same curved continuum, and black holes are treated as pathological monsters. But in this book, we already know a choice of coordinates that does away with all of this: It makes general relativity exactly linear. Spacetime separates from the gravitational field, and as such, black holes are no longer pathological… They are particles!

What gets missed in this discussion of what I call the black hole particle duality is that even though we singled out a set of coordinates, the black hole equations are still solutions of general relativity. Therefore, we didn't kill general relativity. What we did was discover a coordinate system within general relativity with some interesting properties. Since we are still obeying general relativity, which is a classical field theory of the gravitational field, means one thing… The particle solutions describing black holes emerged from a field theory of gravity. We have our first example of particles emerging from a field!

So General Relativity gives black holes as particle solutions directly. Now since general relativity is a field theory, it must have field equations it obeys. Here they are:

$$R^{\rho}_{\sigma\mu\nu}=\partial_{\mu}\Gamma^{\rho}_{\nu\sigma}-\partial_{\nu}\Gamma^{\rho}_{\mu\sigma}+\Gamma^{\rho}_{\mu\lambda}\Gamma^{\lambda}_{\nu\sigma}-\Gamma^{\rho}_{\nu\lambda}\Gamma^{\lambda}_{\mu\sigma}$$

This is the Riemann Curvature Tensor. It is full description of curvature, which we define here as how much parallel transport along a square loop changes any basis vector. It has 4 indeces each of 4 components, which means it is a tensor with 256 entries!

$$R_{\nu\rho}=R^{\mu}_{\nu\mu\rho}$$

By summing over mu, we arrive at the Ricci tensor, which is our first tensor to be used in our field equations.

$$R=g^{\mu\nu}R_{\mu\nu}$$

By contracting with the inverse metric, we arrive at the Ricci scalar, which is the only term of the Einstein-Hilbert action. The resulting extremum of this action is given by the Einstein Field Equations for the vacuum. Here it is:

$$R_{\mu\nu}-\frac{1}{2}R\,g_{\mu\nu}=0$$

What should become clear is this: Although this field theory describes gravity and spacetime, the particle solutions, when quantized, don't give the same equations. If they did we would have a graviton particle with spin 2 and massless. Gravitons would as such destroy our coordinate system and with it our theory. But by quantizing any other field theory, the resulting particles do actually give the same equation.

It is this fact that allows one to only apply quantum physics to our black hole particle solutions of the gravitational field and not to spacetime itself. If one did try and quantize the full nonlinear beast of general relativity, we would end up with string theory or loop quantum gravity, which is not only beyond our scope of topics, but is also wrong, because they contain gravitons which can never be detected. By quantizing our black hole particles, and not general relativity, we circumvent a critical issue in modern physics: Quantum Gravity! So lets now move on from this quantum gravity nonsense and quantize an actual field theory that does have a particle interpretation that actually works…

Example Field Equation

Here is a great example: The Klein Gordon equation in 1 dimension. Not 3D like our spacial universe, just a classical field theory along a straight line, like a guitar string.

$$\left(m^2+\frac{d^2}{dt^2}-\frac{d^2}{dx^2}\right)\phi=0$$

We now have an equation that we can use to run though the gauntlet.

Example Operator

First up is the operator. If we apply an operator to our field we get back at the klein gordon equation. Which is the spinless version of quantum relativity. If we take the square root of this operator, we arrive at the 1D dirac operator with only t and x gamma matrices. Applying this dirac operator to another field we get the dirac equation, which is the spin half version of quantum relativity. Operators have many uses in quantum physics.

$$m^2+\frac{d^2}{dt^2}-\frac{d^2}{dx^2}=\hat{O}$$

Here is the 1D klein gordon operator. It's just the equation without the field. Now lets move on to quantizing our field theory.

Quantum Physics of a Field Theory

Our 1D klein gordon equation is the classical limit of another equation. That is to say if we apply quantum physics twice, we arrive at the following equation. The particle trajectory is without any quantum physics. Then after quantizing once, we get the klein gordon operator. After that, be reapplying quantum physics again, this time to our klein gordon field, we arrive at a new operator.

$$\hat{H}=\frac{1}{2}\int dx\left(\hat{\pi}^2+\left(\frac{d\hat{\phi}}{dx}\right)^2+m^2\hat{\phi}^2\right)$$

Shown here, this is the shrodinger wavefunctional hamiltonian. The hats denote operators, and the hamiltonian is the total energy of a system and is a function of a function. Twice over, do to our notion of quantizing a field theory.

$$\hat{H}\Psi = i\frac{d\Psi}{dt}$$

As usual from the shrodinger formalism, energy is simply the frequency of the wavefunctional.

$$\hat{\pi}\Psi = -i\frac{d\Psi}{d\phi}$$

And instead of linear momentum of a particle, we have the linear momentum of the field. It's the time derivative not of position, but of the field value.

$$\hat{\phi}\Psi = \phi\Psi$$

And here we get to the field value itself.

$$i^2 = -1$$

And we redefine the imaginary unit in this formalism.

$$1 = \int d\phi\, \bar{\Psi}\Psi$$

Where, the wavefunctional across all spacetime is normalized to one across all field configurations within it.

Quantum Physics of Multiple Particles

The reason for quantum fields is simple. We arrive at particles that obey the same equations as the fields themselves. Instead of a single field, we have many branches of the wavefunction. But the klein gordon operator went through the gauntlet unchanged. It is here that we create the duality between black holes and quantum particles.

$$\left(m^2 + \frac{d^2}{dt^2} - \frac{d^2}{dx^2}\right)\Psi = 0$$

Lowercase varibles for the first particle.

$$\left(M^2 + \frac{d^2}{dT^2} - \frac{d^2}{dX^2}\right)\Psi = 0$$

Uppercase variables for the second particle.

$$1 = \int dt\, dx\, dT\, dX\, \bar{\Psi}\Psi$$

All acting on a single high dimensional wavefunction that has multiple spacetime copies, each branch being a single particle wavefunction. These particles are energy harmonics from our quantum field.

Quantum Physics of a Single Particle

Here is the version for a single particle.

$$\left(m^2 + \frac{d^2}{dt^2} - \frac{d^2}{dx^2}\right)\Psi = 0$$

As we can see, its the same exact equation. It doesn't matter if you want to describe a single quantum particle, or a classical field. Both obey the same equation. The klein gordon equation in 1D in this case.

$$1 = \int dt\, dx\, \bar{\Psi}\, \Psi$$

But unlike the field case, we have to normalize the wavefunction to order unit across all 4-volumes of spacetime, which here in 1D is only the t by x area.

The problem with particles

What is a particle? Newton thought that particles are tiny points. Even Einstein's theory predicts black holes as points. However by that time, science has caught up, but every scientist continued to believe in point particles. Even with the birth of quantum theory, the point particle persists. Why? Could we be wrong all along? The answer is a resounding yes. As it turns out, reality is not made of particles at all… But something else: a field!

To really see the significance of such a paradigm shift, we first need to come to grips with what a quantum particle even is. Every quantum theory begins with a single equation: The schrodinger equation. This equation is what one gets when one applies quantum physics to a single particle. In other words, it is the quantum version of Newton's point particle! Interpretations aside, the schrodinger equation is actually a field equation. A field is just a mathematical object that takes a value at every point in space, just as a particle is a mathematical object with a position in space. It is that simple. But, the details matter here, such as why the schrodinger equation has so many people baffled about what a particle is.

For quantum physics 101, we recall how to apply quantum physics to a point particle. Back in classical physics, we know a particle is an actual point that travels in a straight line with a constant speed. Just like a billard ball. It has linear momentum, and kinetic energy. The momentum is just its mass times its velocity vector. Whereas the kinetic energy is simply half of the dot product between its velocity and its momentum. However, the shrodinger equation tells the same story, with a central modification. The solutions of the equation are now sine waves, with their wavelength inversely proportional to their momentum, and their frequency directly proportional to their kinetic energy. By adding many sine waves together, one can create wave packets: Traveling waves that look like a collection of point particles from a great distance.

However, most scientists didn't see it that way. They invented a slew of new methods to coax particles out of the wave equation. Lets examine each case, one by one. So here we return to our original question: What is a particle?

One way is to reinterpret the wave equation as describing not a field, but a probability wave, known as a wavefunction. The amplitude squared of the wavefunction gives the probability density of finding the particle in space. Therefore during measurements, the wavefunction "collapses" to a single point of interaction. This collapse gives us the definite position for our point particle. But this gives new problems. Since the collapse is a result of a single measurement of a single particle, means one thing: One must introduce new dimensions of space to handle more particles… 1 particle is 3D,

2 particles is 6D, 3 particles is 9D, 4 particles is 12D, and so on… This phenomenon is known as quantum entanglement, or spooky action at a distance. And this is used to compute corelations between multiple particle probabilities.

Another way is to keep our original interpretation of the wave equation as describing a field. From this, we apply the whole procedure of quantum physics all over again, not to our point particle, but to the entire field! The "quantum" field as it is called, has an infinite number of dimensions, each one describing the value of the field at a particular point in space. Each sine wave in the field, has a physical amplitude, just like the position of a particle. Therefore, the resulting "quantum field" is an infinite collection of coupled quantum harmonic oscillators, and is no different than our original use of wavefunctions for describing the system. Then, the energy levels of each quantum harmonic oscilator, corespond to a collection of identical quantum particles. From this, we have come full circle, as "quantizing" the field, gives the same result as reinterpreting the field as a multiple particle wavefunction. Something seems off here, due to the persistence of point particles.

The reason for using quantum mechanics then has nothing to do with the shrodinger equation itself, and rather is all about the probabilities of measurements having to do with some sort of wavefunction, which lives in an abstract space of possibilities known as a hilbert space.

We should pay attention to what the schrodinger equation is actually describing, and not force particles into our paradigm. By doing so, we lose track of what reality is, as human centric constructs enter our most fundamental theories. Particles are just one example of this. In everyday life, we see solid objects in motion: Particles. And objects move through a physical medium: Space. If particles are such a human centric construct, we have to make sure that this doesn't creep into physical theory…

However, there is more to the shrodinger equation than this! Every relativistic wave equation, reduces to the shrodinger equation in the domain that the speed of light becomes instantanious. So, if the shrodinger equation describes a field, and this field is what one gets in this regime where the speed of light tends to infinity, means one thing: All relativistic wave equations describe fields too!

And it is this idea which makes some serious sense. Here's why… The standard model of particle physics, believe it or not, is a field theory. If one took the field equations, and run them on a supercomputer, that would be all that is needed to simulate the universe. The fields equations are just relativistic wave equations, or otherwise put, versions of the shrodinger equation, that obeys Einstein's theory of special relativity. In the regime where the speed of light becomes instantanious, does one recover the shrodinger equation. Therefore the shrodinger equation is not fundamental to quantum physics, but instead, all of quantum physics including the shrodinger equation emerges from relativistic field equations. Classical Field Theory is more fundamental than Quantum Mechanics! And the standard model, is exactly that: a classical field theory.

Since quantum theory is emergent, there is no need to apply it to a theory which is already "quantum" in nature. Therefore the standard model is a theory which satisfies both quantum physics and relativity. It's that simple!

For Fermions of Matter

Now we arrive at a new idea… What if quantizing the field is the wrong approach, what if one only needs to reinterpret the classical field theory in this new quantum particle perspective. So instead of branches of the wavefunction for quantum particles, or harmonics of a quantum field oscilation, we use our new approach of classical fields as fundamental. What if a classical field is "quantized" not by actually reapplying quantum mechanics to it, but rather is quantum by its very nature. For particles with spin half, we quantize the dirac operator by using an equation with the following matrices. The equation is defined at the end of the math sections.

$$a=\begin{pmatrix}0 & 1\\ 0 & 0\end{pmatrix}$$

This is the fermionic creation operator, written in matrix form.

$$\bar{a}=\begin{pmatrix}0 & 0\\ 1 & 0\end{pmatrix}$$

Same thing but for destroying a fermion.

$$Z=\begin{pmatrix}1 & 0\\ 0 & -1\end{pmatrix}$$

We have the parity operator which appears when swapping any two fermions.

$$I=\begin{pmatrix}1 & 0\\ 0 & 1\end{pmatrix}$$

And the unswapped version. For many classical fields in tandem, each degree of freedom at a single spacetime position has its own creation and destruction matrix.

$$A_k=\ldots\otimes I_{k-1}\otimes a_k\otimes Z_{k+1}\otimes\ldots$$

Here are the creation matrices. Using the tensor product one can contruct 2^N dimensional matrices, each an option for the number of particles in each field for the wavefunction.

$$\bar{A}_k=\ldots\otimes I_{k-1}\otimes \bar{a}_k\otimes Z_{k+1}\otimes\ldots$$

Here are the destruction matrices. They too use the tensor product, sometimes called the Kronecker product.

For Bosons of Force

Given fermions can be quantized like this, bosons like our klein gordon equation from earlier can also be quantized, and are done so by again, multiplying by the matrices. It is just that the matrices are infinite dimensional.

$$a=\begin{pmatrix} 0 & \sqrt{1} & 0 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & \sqrt{2} & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & \sqrt{3} & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & \sqrt{4} & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & 0 & \sqrt{5} & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \sqrt{6} & \dots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sqrt{N} & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \infty \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

The creation matrix. Notice the square roots, this is important for later.

$$\bar{a}=\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 \\ \sqrt{1} & 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & \sqrt{2} & 0 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & \sqrt{3} & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & \sqrt{4} & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & \sqrt{5} & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & 0 & \sqrt{6} & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \sqrt{N} & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \infty & 0 \end{pmatrix}$$

The destruction matrix. Which also has square roots just transposed.

$$I=\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

The parity matrix. Which is just the infinite identity matrix.

$A_k=\dots\otimes I_{k-1}\otimes a_k\otimes I_{k+1}\otimes\dots$

The creation matrices in full.

$\bar{A}_k=\dots\otimes I_{k-1}\otimes \bar{a}_k\otimes I_{k+1}\otimes\dots$

The destruction matrices in full.

Fermions Anticommute

What is important is that the matrices follow quantum poisson brackets, such that the matrices when mutiplied will give a quanized theory. Fermions anticommute.

$A_k \bar{A}_k+\bar{A}_k A_k=\delta_{kk}$

There is a quantum uncertainty between the creation and destruction operators for fermions, as the matrices anticommute into the identity.

$\bar{A}_k \bar{A}_k + \bar{A}_k \bar{A}_k = 0$

Fermion destruction anticommutes.

$A_k A_k + A_k A_k = 0$

Fermion creation anticommutes as well.

Bosons Commute

The same quantum rules must also apply to bosons. While fermions antimcommute, bosons commute.

$A_k \bar{A}_k - \bar{A}_k A_k = \delta_{kk}$

There is also a quantum uncertainty between the creation and destruction operators for bosons too. Here they commute into the identity.

$\bar{A}_k \bar{A}_k - \bar{A}_k \bar{A}_k = 0$

Creation of bosons commutes.

$A_k A_k - A_k A_k = 0$

Destruction of bosons also commutes.

The Equation for a Relativistic Quantum Field

Okay, so we ran through the standard prodedures of quantum field theory. What makes this interesting here, is that instead of the quantum fields being a bunch of operator valued distributions, like the second quantized field theory from earlier. We keep the operator intact, and use what we learned from the duality between a single classical field and multiple identical quantum particles to describe reality without ad hoc quantum rules.

Here is the equation that describes the quantum field, and as you can see, it has no operators or wavefunctions. Just a classical field theory and its operator applied to its cooresponding matrices. If you have heard of the schwinger-dyson series expansion for calculating the feynman scattering rules, you might have seen this equation:

$\hat{O}_N A_N \Psi = \bar{A}_n \Psi$

However, instead of using the generating functional, which is a kind of wavefunctional for particle creation and destruction through field excitations, why not reapply the same concept of particle creation and destruction to the creation and destruction of discrete field quanta within a single classical field theory.

Here is what I mean. Lets say for example we have two classical klein gordon fields, lets call them phi_1 and phi_2. Each classical field operator must multiply to a given phi. 1 or 2. If a field operator multiplies to phi_1 we use the 1st creation operator. Whereas if it multipies onto phi_2, the 2nd creation operator is used. If we had a third field phi_3, we would multiply its operator onto the 3rd creation operator.

Given that we have 28 bosonic fields in the theory of everything, we would have to kronecker product 28 matrices, 27 being infinite identity matrices on either side, and

one being the infinite creation matrix, giving us 28 creation operators. Every time we see a classical field phi, we multiply it by its own creation operator.

This explains why in interacting theories, where a phi_2 might appear in phi_1's equation we don't use the 1st operator. No we use the 2nd operator for phi_2, even though it appears in the 1st equation for phi_1. This is how interactions happen. Then when all the fields in each field equation are all multiplied by their coordponding field operators, we include a source term which is the destruction operator for the coorepsonding equation in its entirety.

This includes the 90 fermionic fields in the theory of everything. Since they have to interact with the bosonic fields, we will see creation operators and fermionic operators being tensor multiplied sometimes up to 3 or 4 times at once. When a fermionic field appears in a bosonic equation, we use the fermionic creation operator for that precise fermionic field inside the bosonic equation sourced by its own bosonic destruction operator. This is why I made the distinction between the field labeled by capital N, and its equation labeled by lowecase n.

Since the field operators are applied to the creation and destruction matrices in sequence, means that each row of the huge matrix cooresponds to a given number of particles in all of the fields. For example going back to our two klein gordon fields. phi_1 and phi_2. The creation operator for phi_1 acts on a wavefunction which is discrete in the number of phi_1 particles and the number of phi_2 particles. The same goes for the phi_2 matrix equation.

This means that each and every field has the particle content of all the fields, as all fields are connected to all others through their particle content. For this to work as a single classical field theory however, one needs to apply a discretation rule to the fields. The greater the amplitude is for a given field-wavefunction the more likely the single classical field will jump to that configuration. Let me explain:

Lets say we have the klein gordon equation for the residual higgs field. And let us imagine that for some reason, its operators have evolved to a state with plenty of electrons and photons. Say for example, 100% probability of a state with 5 electrons and 3 photons. What would 5 electrons and 3 photons look like in the fields we started with. Well since there are 0 higgs bosons, the klein gordon equation will flatline. The 5 electrons will all occupy distinct plane wave modes of the electron's Dirac equation, each plane wave with an amplitude of unity. For the 3 photons however in Maxwell's equations, they could occupy a single mode with an amplitude of root 3. Or two photons could occupy one mode with an amplitude of root 2, with the third photon occupying another mode with amplitude unity, or like the dirac case, all photons could be in separate modes with amplitude unity.

The point is that the operators are not physical reality, they act on a wavefunction that tells you the likelyhood that the field will collapse to a given configuration. And the wavefunction amplitude squared gives that probability. Which is

then normalized to one for all spacetime. Then one rolls the dice so to speak, and the fields are updated to their correct new values. But how does one know that the classical fields are discrete in the first place. To do that we need to solve the measurement problem, and bring up some old quantum theory do to it. What we have here will shock you.

A Solution to the Quantum Measurement Problem

In standard quantum field theory, one promotes field values to operators that act on a wavefunction of field configurations. However, as we know, this leads to issues related to the fact that standard quantum theory is an emergent phenomenon. So what do we do? We see particle trajectories in particle colliders, atoms in electron microscopes, and photons of light in the photosensors of a digital camera. What is going on here?

The answer might not be what you expected, since reality is all classical fields, we cannot afford to reintroduce quantum theory, to make particles pop out. Moreover, the introduction of quantum physics to matter fields like the Dirac equation, leads to other issues like the use of anti-commuting variables. These "numbers" don't have a wavefunction associated with them, so altogether, we lack a particle interpretation anyways, and the fields are treated inconsistently. However, there is a loop hole.

Whenever we see a "particle", what is going on is that the field has been localized. After all, wave packets, do act like particles. What if, it is possible for fields to collapse. Not like wavefunction collapse, but in a different way, that I call field collapse. This is similar to a Jpeg image file. The image is the field. One takes the fourier transform to find the frequencies that make it up, and then rounds their amplitudes. The result is stored on the computer's storage drive. This introduces discrete amplitudes, for all field modes. What we are doing is much the same.

To be rigorous, there is a theory known as the old quantum theory. Each fourier mode of a field is just a sine wave, as we discussed previously. Since these sine waves are solutions to a simple harmonic oscilator, we need to find the "old quantum" counterpart. The process of quantizing the harmonic oscilator, in standard quantum theory only produces the wavefunction for bosons, not fermions. However, the old quantum theory does describe both bosons and fermions. For bosons, one has the commutation relations, and for fermions, one has the anti-commutation relations. These are the same relations that gave us the anti-commuting numbers, and harmonic oscilator wavefunctions. But with a twist…

Instead of quantizing everything, we discretize everything. Since all fields are relativistically invariant, one only needs to quantize a field mode in its rest frame, and then one can lorentz boost to any other frame. This ensures that the field mode amplitudes are all unchanged by a change in perspective. Thus a field mode at rest, is just a single sine wave, vibing at a frequency of its rest mass energy.

Applying the old quantum theory to such a sine wave, one selects amplitudes whose square is an integer. Just like the wavefunction squared gives a probability that integrates to one over all spacetime, here the total value is an integer, as we are dealing with multiple levels of energy, each one a discrete field quantum: A particle.

What makes this interesting, is that the transition matrices used for quantizing a harmonic oscilator, are the exact same that are used for the discrete harmonic oscilator. For field theory, these are the raising and lowering operators. But here, we are using these matrices to select discrete amplitudes for our field modes. The amplitudes are all square roots of the integers. For bosons, the whole numbers are allowed. For fermions, they are the binary numbers which are allowed. Therefore Qbits, in quantum computing, are just these anti-commutation relations.

So, from this, one can discretize the field modes. But a question arises, how does this reproduce the Pauli exclusion principle, and the stats for particle exchanges with varying degrees of spin? Since each fourier mode, has an uncertainty principle built in, with each sine wave having a definite momentum, implies that matterial fermions must take up space. Why? Since the mode amplitudes must be binary, and since they are states with definite positions or definite momenta, but not both, means that cannot overlap, because this would mean the ampltudes would be greater than one. Therefore, the exclusion principle is derived directly from the anti-commutation relations used not to quantize but to find discrete binary amplitudes for each field mode.

For bosons its a similar story, as their harmonic oscilator amplitudes are all resulting from the use of commutation relations. The same statistics, the same polarizations, the same exclusion principles, the same everything as the standard theory, but just a discrete classical field theory. For the spin stats, one must realize that it takes two full turns for a spinor to complete its rotation, but a vector takes just one full turn to do its rotation. This is the same reason why the exchange symmetry works for both bosons and fermions. Whenever we observe a field, it takes on discrete values. But what discrete values does it take?

Imagine the setup. You reading this, are in a simulated virtual universe. The VR headset tracks your movements, and the screens update. Its the same here. The fields you see are discrete because of the VR headset. Without you being here, the fields will continue their evolution determined only by previous updates. Therefore as soon as consious observers evolved on our world, the spaceship earth, was the time that the fields started to collapse to discrete values.

Taken to its logical extreme, it means one thing, thermodynamic potentials, like that of thermal or blackbody radiation for bosons called photons, or even the electrical shot noise in circuits for fermions called electrons, can be approximated by the fact that at a given temperature, the probability of finding a number of particles is proportional to the exponential of the number of particles. This means that one compares probabilities between any adjacent particle numbers, the probability to have

the extra particle will be decreased by a given multiplicative factor. This is statistical mechanics of bosons and fermions, explained straight from a classical field theory. But what does this have to do with the energy of a particle? Why does two particles have at a minimum, 2 times the energy of a single particle at rest? And why do fermionic fields only allow binary numbers of particles, while bosonic fields only allow whole numbers of particles?

Looking at the matrices, we see why. Each fermionic creation sub matrix is always 2 by 2. Two equations, each with two outcomes. The first outcome is 0 fermions, or empty. The second outcome is 1 fermion, or full. This is the pauli exclusion principle in a nutshell. For bosons, the matrices are infinite dimensional, because any whole number of particles can exist in the field. Each outcome has its own seperate wavefunction. And it is in measuring the number of particles in each wavefunctions that determines what particle content exists in each field.

So we already have a particle interpretation from this classical but matrix field theory. The ladder of energies explains the statistical properties of both bosons and fermions at a given thermal equilibrium temperature. But what about quantum entanglement? What about the fact that fields have uncertianty build into them. Does this ruin our notion of fields being classical?

Not so, and here is why? As it turns out, the matrices themselves carry the commutation or anticommutation properties that would normally be attributed to the quantum fields. The classical fields always are definitive and always use commuting numbers for their values. By taking these fields and mutliplying them by matrices that obey these quantum rules, we have effectively quantized our fields while sticking to classical field theory. This means that we recovered quantum entanglement from our matrices directly and exchange symmetries of bosons and fermions, derive straight from them. And not just that, but because each creation matrix defines the Hermite polynomials for a quantum harmonic oscilator wavefunction for a bosonic field, or the grassmann varibles used for a fermionic field, it is impressive that quantum uncertainty of the fields themselves also lives in its matrix structure.

Now that we have a method for finding our discrete field quanta, its time to use our single classical field theory. In Bohmian mechanics, or pilot wave theory, there is a wavefunction that guides a single trajectory in hilbert space. The gradient of the wavefunction in each of the dimensions gives the momentum of the cooresponding particles. In our theory it's similar with another twist…

Previously, we abandoned quantum theory, and replaced it with a discrete but classical version. So to be compatible with our theory, we have to redefine our pilot wave theory not for a wavefunction, but for our field theory. Now, we still use the same gradient rule, but replaced with a field. Now since there are not 3N dimensions anymore, its seems natural to just let our single field theory, guide multiple independent

trajectories. Not, a single trajectory on a high dimensional wavefunction. But rather is this: Many particles guided by a single field theory!

Here, everything seems fine, so what happens to quantum entanglement and exchange symmetries? Since the field modes are discrete, and since non locality is generated by the trajectories, not the field, means that every particle is indeed coorelated with every other particle. Lets take a closer look to a famous experiment. The double slit experiment!

Here particles are shot into a wall with two slits in it. The particles are detected on a recording screen behind the wall. Since the particles are all wave packets, means one thing: We see an interference pattern on the back wall. The same thing occurs with single particles too. Its only when a single particle is observed before it passes through one slit or the other does the pattern split into a two band pattern of hits, not an inferference pattern of many bands.

What is going on? Are there some spooky things going on? Nope, wrong again. The field theory describes the same thing as the quantum theory, because the field equations are identical to the shrodinger equation. Even for a single particle quantum theory, its the same… And thats why an interference pattern is seen, even when struck one particle after another!

But now, something interesting occurs when one observes it before it passes through. Everything the same, the discrete field theory, collapses just like the wavefunctions do. Therefore its no difference what theory we use, but the field approach is much simpler, and thus must be the correct one!

Turn down the intensity, and fewer particles pass through the experiment at any given time. The field discretness becomes more visible. Until one discrete field quantum is passing through any given time. The pilot wave trajectories are used because the discrete field behaviors are what encodes the multiple particle exchanges. Without the entanglement directly encoded in the wavefunction's phase space, we are free to include multiple trajectories in our field theory. After all, when we turn the intensity back up, we recover the trajectories as actual particles. It's just the fields themselves collapsing, creating the illusion of particles.

Here is how the field collapse algorithm works

1). Take the standard model of particle physics. As sean carroll's core theory, it is a domain specific truth, verified to a great undreamt of precision. Specified by a lagrangian density. Next, Reinterpret it as a classical field theory. Use the relativistic field theory version of the euler lagrange equations, to derive the equations. Then solve them numerically using a fourier pseudospectral method.

2). Introduce discrete field collapse using old quantum theory and the canonical transition matrices. Just like a harmonic oscilator in the old quantum theory, every plane wave decomposed field mode has discrete classical amplitudes, which are lorentz frame

independent. Using canonical commutation and anticommutation relations to derive bosonic and fermionic heisenberg matrices, one can recover the transitions through the coorespondence principle. Not by canonical quantization, but by associating transition matrices with probabilities for discrete field mode amplitudes. For bosons one uses the simple harmonic oscilator in the # basis. For fermions one uses the 2 state quantum system in the Qbit basis. Therefore quantum wavefunction collapse is just the collapse of a single classical field to a superposition of multiple VR consious interaction events.

3). Each discrete classical field quantum is associated a relativistic bohmian trajectory. Not using quantum entanglement nor using feynman rules, which is wrong since they use a single trajectory in 3N+1N dimensions projected down to all N particles. Rather we use a single classical field theory guiding our N trajectories independently. The pauli exclusion principle occurs from the 1st order spinorial nature of the Dirac equations and the lack of it occurs from the 2nd order vectorial nature of the Proca equations. Thus the spin statistics theorem is derived from the fourier modes of collapsed field modes guiding our bohmian trajectories, think of the exchange symmetries but applied to the double slit experiment as a CFT(Classical Field Theory).

4). Each trajectory using the Kerr NP(Newmann Penrose) tetrads in the cartesian Kerr Schild spacetime geometry, sources the spacetime geometry from flat Minkowski spacetime, using the Poincare Gauge Theory, and with it the classical fields are coupled to this geometry. This goes full circle and completes the code. The point is simple, every discrete classical field quantum is by definition a rotating black hole. Using the xKS(cartesian Kerr-Schild) coordinates, one can perform Poincare transformations to spacetime frame hop from one bohmian trajectory in its own retarded time to the other's trajectories calculated from the exactly linearly perturbed classical fields surrounding it. From a global minkowski spacetime with Poincare symmetries, mass and spin, one gauges the symmetry in vacuum resulting in the Kerr geometry, which you guessed it describes particles with mass and spin.

What we have done is separate the quantum stats from a given classical field. Akin to seperating the background spacetime from the gravitational field of a rotating black hole. Its the seperation of classical relativistic fields from their quantum or gravitational counterparts that allows unification of mutliple particles at once! This is why it is possible to start with nothing: The void, look at its symmetries, and define all of physics from it. We have in a sense everything from nothing. A Theory of Everything!!!

Chapter 7: The Theory of Everything

And from nothing emerges everything. The only assumption we made was that of spacetime symmetries. By applying CGH physics to this void, we learned that rotating black holes and discrete field quanta are one and the same. From their field dynamics we can build our universe. Our universe is all there was, all there is, and all there ever will be.

However, with this said, there is still plenty of work to still be done. We need to see how the theory of everything applies to our universe. We will learn that all everyday phenomena arise from the motion of atoms in the void, governed by a given intermolecular potential. From this we can deduce similar processes occuring in deep space, and show how everything from the most common elements to the structure of atoms themselves came about from events that occurred fractions of a second after the big bang itself: 13.8 billion years ago.

We ourselves are a byproduct of the universe's existence, so it's really no surprise that we found ourselves in a universe such as this. The trick is to understand our universe by being able to show that the theory of everything does indeed give rise to the universe we see around us. After all we and everything else follow the same rules. The question then is: What are those unbreakable rules that the universe always obeys to the letter.

The Aether Field Medium

The theory of everything, is all about a material. The aether! Within, exist a chaos of sound waves. As they undulate across space, their vibrations propagate in all sorts of exotic ways. All of this happens automatically, without any sort of divine intervention. The fact is, that the whole cosmos is entirely built out of these waves. In order to find out what these waves can do, lets first analyze their physics. In so doing, we will learn about all of the complex and intricate structures that these waves can form. This truly is, the theory of everything!

The aether's material properties, are what gives rise to these particles in the first place. There is one material property of the aether that is the most important for our story, which is that the aether is a fluid. On large scales, lots and lots of particles can act like a fluid. But what is really interesting, is that the aether itself also acts like a fluid. Therefore, we would expect to find out, that the aether is made of aether particles, on the tinest of scales. It is the collective motions and vibrations of our aether particles, that give rise to sound waves within the aether. Then it follows that the minimum units of vibration, the quanta of sound, are not actually particles as we usually think of them. We call such particles, phonons, after "phone" for sound. Every electron, photon, quark, higgs boson, and every thing else, are all aether phonons. On the other hand, the aether itself is a different kind of fluid, consisting of its own particles.

So just like how some phonons, be it electrons in electricity, photons in light, and composites of quarks in nuclear matter. We now know, that the actual particles that the aether is made of, should reflect the fluid properties of the aether itself. Well there is such a thing. Gravity!

The ripples in the aether may describe matter, but the flow of the aether itself is the most important thing of all. Gravity. On large scales, gravity is the universal attraction of everything with everything else. This attraction looks and feels like a force. However there are no mediating particles to carry the force. Hypothetically, this so called graviton, would have a spin of two, and would move at light speed. It isn't so easy, because gravitons do not exist. This is because we already used up all the aether phonons in the form of other particles. So how does a fluid aether give rise to gravity, without gravitons? Lets find out!

The aether is a fluid like substance. It responds to the pressure, density, flow, and viscocity, of the sound waves within it. This response causes a curvature, or flow gradient in the aether itself. This is just like a whirlpool, sucking the aether down the hole. Far away from the hole, the gravity is weak, and the flow of aether towards the hole is very slow. Closer in however, the gravity increases like a rip tide, dragging sound waves into orbit. At a close enough distance from the hole, the aether flows inwards faster than the sound waves can propagate outward. Everything within, is trapped forever. This is the event horizon of a black hole! Therefore, these aether particles, are not vibrations within spacetime, but as a particle constituting space itself. So to summarize, matter tells spacetime how to curve, and spacetime tells matter how to move. In reality, sound waves tell the aether how to flow, and the aether tells the sound waves how to vibrate. Every aether phonon, is its own black hole.

How black holes are fundamental particles

All of these digital wave quanta, which I will just call particles from now on are the foundation for not just us, but the entire history of the entire universe. We mentioned how quantum mechanics emerges from the wave like nature of particles, and this is because everything is just waves all the way down. We mentioned how mass and spin determine the properties of the waves, such as their frequency, wavenumbers, and polarization states. Ultimately special relativity sets the stage of spacetime, the backdrop of reality itself, with the mysterious property of the speed of light remaining constant no matter the circumstance. This is what causes time to square to a negative number. It is this underlying fact about the geometry of spacetime, that shapes these waves into existence.

But how can this be, and why does it happen? The answer might surprise you that every particle is litterally a rotating black hole. Any black hole by definition is a region of space where the gravity of the space is so strong the nothing not even light can escape from it. Black holes that spin on an axis are called rotating black holes. These

rotating black holes have the same mass and spin as the wave they represent. It is this mapping of particle properties to rotating black holes, that creates gravity.

So there we have it, gravity, relativity, quantum, all unified into a framework that describes reality in terms of waves. Relativity tells the waves how to vibrate given their mass and spin. Quantum effects digitize the waves into discrete particles. Gravity emerges from the fact that every particle with a given mass and spin is a black hole with the same shared mass and spin.

An introduction to the unified field theory

As it turns out, a wave can only affect other waves nearby. This means that it takes some time for a wave over here, to influence a wave over there. The sphere of influence grows at a constant speed. This speed is the speed of light. Since light speed is always the same, means that from a moving perspective, it is time itself that runs slow. As such, space and time are unified into a new framework. Spacetime! This is how special relativity enters our understanding of the universe.

Imagine finding a concentrated lump, or packet of waves. Seen from far away, this so called wave packet, looks very much like a dot, moving in a straight line with a given speed. A particle. However, "particles" act very strangely at microscopic distances. They act randomly, yet also are in many places at once. How can this be? This is because they are not particles, but waves. After all, waves are spread out entities. So it makes sense why particles seem to act like this. This wave like nature is in the foundation of quantum physics.

In what follows, almost all everyday phenomena, from that of chemical reaction rates, to the way viscous fluids flow, will be determined by how two types of waves interact. They are the electronic waves and the optic waves. The optic waves and electronic waves can only support a discrete number of quanta. Any wave is a superposition of plane waves, and the amplitude of each plane wave is directly proportional to the square root of the the number of quanta residing in it. Electrons of electricity are the quanta of the electronic field and can hold only binary numbers of quanta. Photons of light are the quanta of the optic field and can hold any whole number of quanta.

So, given this, the electronic waves and the optic waves can act very differently. Electronic waves, have a property called mass, whereas optic waves do not. All waves with shorter wavelengths, tend to vibrate with a faster rate, or frequency. It is this excess frequency, in addition to its frequency due to its wavelength, that is the mass of the waves. There is a formula for this excess hum, and it goes as follows: The mass of a wave squared is directly proportional to a difference of squares, similar to the pythagorean theorem, just backwards. It is the frequency squared minus the magnitude of the wavenumber squared. It is the fact that time squares to a negative number respect to the three dimensions of space, that is the key definition of special relativity.

This is the reason why some waves, have the property that they can vibrate faster, yet be very spread out. These waves are our electronic waves.

However, there is more! Mass isn't the only property that waves can have. Waves can also have a property, known as spin. That is to say, that the direction that the waves are vibrating in, its polarization, depends on our point of view. The amount of spin, takes on discrete values, of zero, one half, one, one and a half, two, and so on. For example, we say that, electronic waves are spin half, because it takes two full turns for their polarization vectors to take one full turn. On the other hand, optic waves are spin one, because under a full turn, its polarization vectors also take a full turn. Otherwise put, the more ways, or degrees of freedom, the greater the spin. As is turns out, in the general case, quanta with odd multiples of spin half all have binary numbers of quanta in each of their plane waves, and quanta with even multiples of spin half all have whole numbers of quanta in each of their plane waves.

Back to electrons and photons, the electronic waves can also experience electromagnetic forces, meaning that they can push and pull on each other. This happens, because electronic waves and optic waves, can interact. If we take two electronic waves, placed some distance apart. They might attract one another, because both electronic waves are disturbing the optic waves in between. This interaction between two electrons and one photon is why we exist, and is characterized by the electric charge.

The vibrations that make up everything

We have already met the electrons and the photons. Electrons interact with photons, because they have a property known as the electric charge. The electric charge of electrons is either positive one or negative one. The matter electrons are all negatively charged. The positively charged electrons are the opposite of matter, known as antimatter. Matter particles and antimatter particles can cancel eachother out, in a violent release of light energy. We say that photons, particles of light, are carriers of the electromagnetic force. After all, light waves are electromagnetic waves. Photons are themselves electrically neutral. The electric charge is not the only charge that exists in the cosmos. There are two others, the flavor charges, and the color charges.

There are four flavors of fermions, the up and down quarks, and the charged and neutral leptons. The electrons are an example of charged leptons. Every up quark has an electric charge of positive two thirds, and every down quark has an electric charge of negative one third. Like electrons, the antimatter quarks also have opposite electric charges. Just like how photons interact with electric charge, there are three other bosons that interact with the flavor charges. These bosons carry a force known as the weak nuclear force, and interconvert flavors into one another. Unlike photons, which do not self interact, the bosons which carry the weak nuclear force, certainly do self interact. We call these bosons, the W plus, the W minus, and the Z zero.

Then there are the color charges. Quarks are the only fermions with color charge. They come in three varieties of red quarks, green quarks, and blue quarks. The gluons interact with these three color charges. They carry a force, known as the fundamental strong nuclear force. The leptons no not experience the strong nuclear force, because they are color neutral, and as such, do not interact with gluons. Gluons, like quarks, have a color charge. In fact gluons come in eight varieties, with each kind of gluon having a unique color charge. This means that like the W and the Z bosons, gluons self interact. Gluons have a color charge of a given color, say red, and a given anticolor of a different type, say anti green. So a possible color charge for a gluon is red anti-green.

As usual, there is more to it than this. Each flavor of fermion, has three possible amounts of matter, or mass. The up type quarks, are the up quarks, charm quarks, and top quarks. The down type quarks are the down quarks, strange quarks, and bottom quarks. Electrons also have two heavier versions, the muon, and the tau. Why? The answer is the interaction with a particle known as the Higgs boson. It is very heavy, and has an unusual spin of zero. All of the other bosons, interact with charges, and have spin one. The higgs bosons don't carry forces, but they do give mass to the other particles that have it. There are exceptions though. The neutral leptons, we call neutrinos, don't have mass, unlike all the other fermions. The photons are massless, along with the gluons, which also are massless. However like the higgs boson itself, the W and Z bosons do have a huge mass. Therefore, the higgs boson interacts with itself.

Concluding Remarks

The scale of the universe is far beyond our day to day experience. To find out what happens in such domains, we need to grasp the three pillars of modern science: gravity, light speed, and quantum waves. Black holes render compatible these three pillars into a single mathematical framework. Because of this unity, fundamental particles with mass and spin are all rotating black holes. This very definition follows straight from the idea that the geometry of space and time is all there is to know about reality. In fact, all of these fundamental particles are nothing more than discrete ripples in fields. The quantum physics of particles, and its observer effect, all emerge from a universe made of fields. In a sense, everything including light, electricity, and matter comes from the shape of nothing itself. A scientist once said: "I think we have it." We finally have the theory of everything!

From this theory, one can compute everything from the way viscous fluids flow to the chemical reaction rates of the elements made in the big bang. Inter-molecular potentials determine how the behavior of atoms in motion within solids, liquids, and gasses, gives rise to material phenomena such as movement, sound, and heat. As it turns out, it is interesting to look at how gravity affects this fluid motion on a large scale, forming the cosmic web, galaxies, stars, and worlds with life. If one took a census of everything in the universe and weighed it, one would find out that 84% is primordial

black holes, 12% is protons of Hydrogen-1, and 4% is alpha particles of Helium-4. The atomic structures of hydrogen and helium, are formed from their interactions with both electrons of electricity and photons of light. All of this amazing complexity comes about from processes that happened in the first moments after the big bang. And yet, from all of us, all of this might just be a computer simulation…

Chapter 8: Fluid Dynamics and Chemical Reactions

Atoms in Motion from an Intermolecular Interaction

All material things are made of atoms. All atoms move in perpetual motion. They weakly attract one another when close, but repel each other strongly when squeezed too close. This pattern is known as an inter-molecular potential, and is key to understanding the phenomena of solids, liquids, and gasses.

In gasses, the atoms are scattering off one another in all directions, colliding like a game of cosmic pinball. This is what a gas actually is. But, on the other extreme we have solids. In solids, the atoms are all stuck together in a regular lattice of rows and columns, and cannot move around. In liquids however, the atoms are able to move around, sliding past each other, but cannot break free all together. This is what makes something a liquid.

With an intuitive grasp of atoms in motion, it is interesting to look at the characteristics that this motion can take. For example, imagine a cluster of atoms vibrating at a bunch of different frequencies. Such waves in the atomic structure of a material are called sound waves. Sound waves with a high frequency or pitch have a short wavelength, while sound waves with a low frequency and low pitch have long wavelengths.

Heat is also atoms in motion. In fact, it's the random motion on the scale of the atoms themselves. Therefore, the very highest frequencies of sound are actually modes of vibration that constitute the temperature of an object. In other words, remove all high pitched sounds within the material, including the sound waves with wavelengths on the atomic scale, and the temperature would drop to absolute zero.

The sound spectrum also continues to the low end with very long wavelengths and very low frequencies. We can also think of vibrating atoms in terms of their period of oscillation. A material object that moves back and forth slowly enough, has wavelengths so long, that they cover the entire object at a macroscopic scale. Since the atoms are moving in unison, its no longer a sound wave, but simply the motion of the object as a whole. Yes, even the atoms in a speeding bullet are moving as it flies.

So, as we can see, motion, sound, and heat, are all just different manifestations of atomic vibrations. However, one might imagine what happens if we include just a feeble touch of self-gravity to our inter-molecular potential. Given by Newton's laws of motion and universal gravitation, the interplay between gravity on our fluid will have some interesting effects.

On a small scale, gravity is negligible. But as we zoom out, the amount of atoms in our view increases, and the amount of gravity accumulates. Eventually, as we zoom out past the scale of entire worlds, and we can treat each world as a single object, accelerating objects toward it, according to the inverse-square law in 3D space. It's this self gravity of large enough worlds, that makes them spherical, such as the Earth itself.

And it is also the reason the solar system holds together. But don't even get me started on the complicated dynamics that gave birth to our solar system.

Take an expanding cloud of gas, with atoms that obey the inter-molecular potential and also Newton's gravity. The gasses first cool down, and tiny grains form, like a cloud of snow particles. As the cloud fragments, the particles collide and stick, with larger fragments orbiting around one another. Within a relatively short time, you end up with a cosmic web, filled with galaxies that look like spinning pinwheels, and within each galaxy, solar systems containing stars, planets, moons, asteroids and comets, all in orbit around each other. Not bad, because this is exactly what the large scale structure of our actual universe looks like in the first place.

The Universe Abundance of the Chemical Elements

From this idea, all we need is an empty box, that we fill with a gaseous mix of atoms. But one question arises… What atoms do we use, and by how much? By studying the cosmic abundances of the elements, we can determine that by mass, 75% of the universe is Hydrogen-1, and 25% is Helium-4. Almost. However, there are tiny impurities that makes life possible. Lets take a closer look.

These impurities also are atoms. Bigger atoms. Atoms like Oxygen, Carbon, and Nitrogen, which are essential for the building blocks of life. They and all other atoms only adds up to another 2% of the universe by mass. If the total mass of all atoms is a metric ton, roughly only 20 kilograms of these impurities would be needed.

Lets begin with Oxygen. Oxygen is the 8th element on the periodic table. It is a very reactive and corrosive gas, as it needs 2 more electrons to complete its outer valence shell. Burning Hydrogen and Oxygen together, forms water vapor in an explosive crack. Oxygen also forms diatomic molecules, which constitute 21% of our atmosphere. So, air, water, and even rocks contain lots of oxygen. So lets add 10,420 grams of Oxygen-16 to our box.

Next up is Carbon, Carbon is the 6th element on the periodic table. Commonly seen in soot or charcoal as graphite, it needs 4 electrons to complete its outer shell. Hydrocarbons such as Methane, are what happens when carbon and hydrogen combine. Carbon Dioxide, are what happens when carbon and oxygen combine. In fact carbon can form more molecules and compounds, than all other molecules without carbon combined. Carbon is therefore the next element that is essential for life. Lets now add 4,680 grams of Carbon-12 to our box.

After this, elements get harder to find. In the case of Neon, it is a noble gas, in the sense that neon atoms don't bond with any other atoms, including themselves. Because its completely non-reactive, means that an atom of neon is a loner. It is the 10th element on the periodic table. Lets include 1,340 grams of Neon-20 to our box.

Iron is the 26th element of the periodic table. It is a transition metal. It is a very dense metal, usually likes to lose 2 or 3 electrons depending on the situation, and is

found in abundance in the earths outer and inner core. On the surface, it is used as the main component of steel, and therefore modern bridges, ships and skyscrapers will be impossible without it. Lets add 1,090 grams of Iron-56 to our box.

Then there is Nitrogen, Nitrogen is the 7th element on the periodic table. The most natural form is of a diatomic gas, comprising 78% of our atmosphere, with Nitrogen atoms needing 3 electrons to complete their outer shells. In Ammonia, it is achieved by combining with Hydrogen. Nitrates are Nitrogen with Oxygen, and Cyanide is Nitrogen with Carbon. Not exactly pleasant, but is also a key component of amino acids in proteins, some vitamins, and even DNA. Lets thus add our 960 grams of Nitrogen-14 to our box.

Silicon is the 14th element of the periodic table. It is a semimetal, which means its properties are between that of a metal and a non-metal. It is this property that makes modern computers possible. Silicon tends to lose 4 electrons to Oxygen, forming a mineral known as Quartz. Glass crystal is just Quartz, and most of the Earth rocks in the Continental Crust are mainly Quartz. Lets add 650 grams of Silicon-28 to our box.

Magnesium is the 12th element of the periodic table. It is an alkaline earth metal. From its name, Magnesium tends to lose 2 electrons to Oxygen, and when combining with quartz minerals, forms a mineral known as Olivine, a green jewel that is a key component of most of the Earth's mass in its Mantle, even including some Oceanic crust. Lets add 580 grams of Magnesium-24 to our box.

Second to last is the stinkiest element, Sulfur. Sulfur is the 16th element of the periodic table. Some common forms of sulfur include hydrogen-sulfide, the gas with the characteristic rotten egg smell, and sulfuric acid which is found in car batteries, and is extremely corrosive. Sulfur combines with other elements in our bodies in many proteins, and a few vitamins. Lets add 440 grams of Sulfur-32 to our box.

Lastly, we have Argon. Like Neon, and Helium before it, it is a noble gas, comes as single atoms, and is completely inert and non reactive. It is the 18th element of the periodic table. Lets finish by adding 200 grams of Argon-36 to our box.

So in short, many of these elements make like possible. With a universe as large as ours, it would be quite strange if earth life is the only life out there. With Oxygen, Carbon, and Nitrogen, in the mix from the get go, alien life should be inevitable. But this is the last 2% of all atoms by mass. Hydrogen and Helium make the atomic majority.

Hydrogen-1 makes 75% of our metric ton box, and Helium-4 makes 25% of our metric ton box. Hydrogen-2 and Helium-3, although stable, are quite rare in terms of mass, but by number, 26.4 ppm is Hydrogen-2 and 10.3 ppm is Helium-3. Also by number this means that we have 750,000 ppm of Hydrogen-1, and 62,500 ppm of Helium-4. Hydrogen tends to form diatomic molecules, and Helium being a noble gas is an inert gas of single atoms. Hydrogen is the 1st element of the periodic table, and Helium is the 2nd element of the periodic table.

But! That is not all there is, and far from it. In fact, remember that all material things are atoms, but that isn't to say that other forms of energy exist out there that

are not atoms. You might be surprised to know that 5 metric tons of primordial black holes have to be added to the box, in order to match cosmological observations. These black holes are essentially invisible and intangible, just like a ghost. This is because the invisible matter that holds galaxies together into the cosmic web, interacts only through gravity. As we know already, a rotating black hole is a particle with mass and spin, just like an electron in an atom or photon of light. In other words, the fleeting existence of quarks and gluons inside the atomic nuclei we discussed are also microscopic black holes. Everything is black holes! It's just that the black holes in atomic matter have properties with such small mass, that they act more like ripples in fields, but nonetheless, the invisible matter that holds the galaxies of the cosmic web together is real.

Atomic Structures and Substructures

As it turns out, every atom of the periodic table consists of a heavy and dense, positively charged nucleus, surrounded by two fields, the electronic field and the optic field. The discrete vibrations of the electronic field are the negatively charged lowmass electrons in atoms, while the discrete vibrations of the optic field are the photons of light, which carry the electric and magnetic forces from one place and time to another. Put together, electrons and photons create all of the solid state and chemical forces within any substance.

Within an atom, the electrons fill "shells" or orbitals two electrons at a time. Each of these orbitals is a standing wave of the electronic field. Since the nucleus is heavy and positively charged, it creates a sink for electrons to be attracted to. The reason why electrons fill one orbital at a time is because they are anti-symmetric under exchange. This is what makes an electron a particle of matter. For comparison, photons of light carry the electric and magnetic forces, because they are symmetric under exchange. Ultimately the reason why electrons are anti-symmetric, rather than symmetric, is tied to the fact that the electronic field itself only transforms half as much as the optic field does under a change in spacetime perspective. But enough about electrons and photons, what is the atomic nucleus anyways? After all, if electrons and photons were all there is, there would be only a single type of atom: Positronium and nothing else, and even then, given that Positronium atoms annihilate by themselves in less than a billionth of a second, what gives?

The answer lies in the fact that there are roughly 250 stable nuclei, and thousands more unstable nuclei. Once we zoom inside the nucleus, we understand that it is a chaos of nucleons and pions. It is said that nucleons are quark triplets, and pions are quark-antiquark pairs. But, in reality, the nucleus is a swarm of quarks and gluons, that are discrete waves in their respective fields, that only resonate fully as composite units. There is much to know as of yet about the field equations, such as their non linear behaviors, which are important to the structure and function of various nuclei, such as

properties like radioactivity and binding energies. But all of the nuclei would not exist, without a chain of events of the early universe, known as the big bang.

Chapter 9: The Big Bang Theory of Cosmic Evolution

The creation of everything

Before the beginning, there was absolutely nothing: No space, no time, no matter. And from nothing emerges everything. Thus, in the beginning, everything is an infinitely dense, infinitely hot, singular point of origins. This mysterious point, is what created everything that follows it, and obeys a set of rules known as the laws of physics.

Lets now pause for a moment and imagine. What kinds of things will emerge from the physics? How will fluids and chemistry come about from mathematics alone? In astronomy, how does order come from the chaos of waves? But for now, to be able to grasp everything that follows, we need to know a few things about physics.

The theory of everything is also known as the unified field theory, because that is what reality is made of: Waves! Put together, these waves described by the unified physics of Special Relativity, Universal Gravitation, and Quantum Mechanics, determine how the entire universe will be built. Now, to see its effect in action, lets turn our attention to the following sequence of events…

In the first tiniest fraction of an instant, the universe explodes into existence, as a rapidly expanding, tremendously hot and dense firestorm, spread uniformly across space, and that extends infinitely in all directions. It is like dropping a nuke in every cubic micron of space, but then to realize that your cubic micron is now a cubic kilometer, as space itself, ever more slowly, continues to expand out in all directions. The universe continues to expand and cool.

In just another few tiny fractions of an instant or so, the tremendously hot and dense, but uniformly spread firestorm that is infinite in extent, has expanded, cooled, and diluted, into a not so hot, not so dense firestorm, that continues to be uniformly spread, and infinite in extent. For some actual numbers, given that our "not so hot" universe, now means ten quadrillion degrees, imagine how incomprehensibly hot the universe was right at the start: ten quadrillion times hotter than ten quadrillion degrees! The universe continues to expand and cool.

So. With this in mind, lets now track the evolution of our particles. Every particle in existence, is constantly smashing into other particles. We say that the particles are in thermal equilibrium. The average kinetic energy per particle, is uniform throughout the cosmos. Looking at the sound waves within the aether, we can see the waves are vibrating with an extremely high frequency. We will measure frequency with a new system of units. The electron volt. Its written as, "eV". Electron volts are useful because they can be understood as, energies, momenta, frequencies, and wavenumbers. In quantum field theory, everything is measured in electron volts. Light speed is 1 foot per nanosecond, and one electron volt of energy corresponds to a wavelength of 1.24 microns. As of now, the weak interaction and the electromagnetic interaction, are one and the same. Moreover, every particle is massless, and moves at the speed of light. This

will change soon, when the temperature drops below 246 GeV. The universe continues to expand and cool.

The higgs boson activation

Passing 1 femtosecond, all of the quarks, antiquarks, leptons, antileptons, and the bosons, are almost in thermal equilibrium, and haven't yet aquired mass from this so called higgs boson. Yet after 10 picoseconds, the temperature drops below the threshold of 246 GeV, and the higgs boson activates. The electromagnetic force carried by photons, is now distinct from the weak nuclear force, carried by the W plus, W minus, and Z bosons. These intermediate vector bosons, along with the higgs boson itself become very massive, on the order of 80 GeV, 92 GeV, and 125 GeV respectively. Since the electroweak bosons interact between themselves, we would expect to find confined states of these bosons. However, now that some of these electroweak bosons have a great deal of mass, removes any possibility of confinement. However these are not the only massive particles around. Every flavor of quark now has three possible masses. There are the up, charmed, and top flavors, and then the down, strange, and bottom flavors. The same applies to the charged leptons, which are the electron, the muon, and the tau. The neutral leptons, the neutrinos, do not have mass, and as such continue to move at light speed. The three top quarks, which are the heaviest flavor of the up type quarks, have masses of 173 GeV. That is much heavier than the W, Z, and the higgs boson. The universe continues to expand and cool.

After the next few hundred picoseconds, the top quarks and antiquarks, higgs bosons, Z bosons, and the W plus and minus bosons, are all gone. The energy of their annhililation, gets dumped into the remaining lighter particles. With these particles out of the picture, the weak interaction, reemerges as a short ranged force, 100 times shorter than a femtometer. In contrast, the quarks and gluons, are starting to feel their presence. This is why we call this the strong nuclear force. This force has litterally several metric tons of strength. The universe continues to expand and cool.

As we pass the ten nanosecond mark, the 4.5 GeV bottom quarks, 1.7 GeV tau leptons, and the 1.2 GeV charm quarks, annhililate away next. This seems like a losing battle, as all of the precious universe building particles, are just dissapearing, one by one, until nothing is left. After all of this, the only massive particles left are, the strange quarks, muons, down quarks, up quarks, and electrons, along with their antiparticles. So, to summarize. In these first instants, all sorts of exotic forms of energy and matter existed, such as quark matter, strange matter, and even antimatter, existed in great abundance. The universe continues to expand and cool.

The formation of primordial black holes

From the time that the Higgs boson activated up to now, which is roughly one microsecond or a millionth of a second after the beginning of everything, there is a tiny

excess of matter particles over antimatter particles. And by tiny, I mean one extra matter particle, be it a quark, lepton, or even a boson, in a cosmic ocean of trillions possibly quadrillions of matter antimatter pairs, that are constantly being created and annhililated. The universe continues to expand and cool.

There shoudn't be a difference at all. Zero, not one in anything, but zero. The fact that the universe went out of equilibrium at all is the question. How did the cosmic balance get violated? To answer this, we need to think about a series of steps that occurred throughout this time period. And it all begins when the annhililation rate exceeds the production rate of matter antimatter pairs, such as when the heaviest exotic particles annhililated away into less heavy particles, and so on. With only the lightest tier of particles present at this point in history, means most of the energy of the annhililation goes into heating the lighter particles by a given fraction. The universe continues to expand and cool.

As it turns out, this extra heat creates turbulence in the plasma of annihiliating particle antiparticle pairs. And this turbulence usually balances out given enough radiation pressure. But whenever we lose further particle species, their isn't quite enough pressure for the plasma to even out. This means that there are moments in the history of our universe from 10 picoseconds onwards to 1 microsecond and beyond, that are going to have turbulence throughout. The universe continues to expand and cool.

When such turbulence persists under the constant struggle of gravity, small pockets of the quark gluon plasma collapse under their own weight, forming primordial black holes with the mass of a mountain at first. Then as the next tier of particles annihilate away, more turbulence is created, and plenty more prmordial black holes are created. These black holes have more mass, about that of a whole planet or large moon. But back then in the first microsecond, it was only a raging firestorm of equal amounts of matter and antimatter. The universe continues to expand and cool.

The creation of new black holes follows when the density overcomes the expansion rate of the observable universe. The observable universe wasn't billions of light years across like it would be by the time this text you are reading was written, no. At 1 microsecond, the size of a universe that would be known would just be the time that information travels in that time. The fastest rate, which is the speed of light in a vacuum, makes the horizon of any observable part of the universe only 300 meters or 1000 feet in radius. Such a black hole would be the mass of a large planet to that of a small star in the modern universe. Inside such a contracting bubble, an event horizon forms, that makes the traversal one way, and a black hole is formed. In any case, the plasma inside appears to go through a big crunch, because there is no knowledge of continued expansionn outside the cosmological horizon. The universe continues to expand and cool.

But with such black holes forming all over the universe, creates huge explosions, at the scale of supernovas or larger, that create enough disequilibrium to force the

imbalance between matter and antimatter. At this point in time, so far not much matter has been created from what seems like the vacuum. But the universe is not a vacuum, its a quark gluon plasma, that flows like the best motor oil, except its temperature is plummenting in from the quadrillions to trillions of degrees. These black holes where what created the first imbalance, that as we shall soon see, will form itself into all of the nuclear matter that will ever exist. The universe continues to expand and cool.

The quarks bind together into hadrons

Then, all of a sudden, right after 30 microseconds, the quarks and antiquarks bind together, into subatomic particles known as hadrons. Hadrons made of three matter quarks are known as baryons, and hadrons made of a quark antiquark pair are known as mesons. The lightest baryons are the nucleons, which have a mass of 940 MeV. The lightest mesons are the pions, which have a mass of 135 MeV. However the up quarks with masses of 2.01 MeV, and the down quarks with masses of 4.79 MeV, that make up these subatomic particles only contribute 1% of the total mass of the hadron. Strange quarks are the only exception to this rule, as they have a mass of approximately 95 MeV. These hadrons are confined, as it is impossible to remove any quarks or gluons for that matter, without creating other hadrons in the process. The fundamental strong nuclear force only acts within one of these subatomic particles, because of this confinement. This confinement is caused by the taffy life gluon flux tubes that emerge from the center of the hadron, and stretch out to the locations of the quarks. Again this is caused by the self interaction of the 8 types of gluons. Most hadrons have a physical size of around 1 femtometer. This is 100 times larger than the weak force can carry. In terms of electron volts, this corresponds to a value of 197 MeV. The temperature is dropping below 200 MeV. The universe continues to expand and cool.

Over the course of a few dozen microseconds after the quark gluon plasma transitions to a baryon meson gas, the resulting subatomic particles are much to heavy to exist, and as such they annhililate away. The small excess of matter quarks over antimatter quarks that are left behind, is now in the form of nucleons, which are the protons and neutrons. This is the very first real tangible matter in the universe. A proton is made of 2 up quarks and 1 down quark, and a neutron is made of 2 down quarks and 1 up quark. Yet these nucleons are outnumbered in the billions by the rediculous numbers of pions, that are being copiously produced in the seething 150 MeV heat. But what is important here is that as all kinds of quarks and all kinds of antimatter quarks, warred for supremacy, emerged a thin excess of protons and neutrons: The particles of matter we know today. The universe continues to expand and cool.

Yet the temperature not going to be this hot for long. So as the temperature drops below 135 MeV, pions begin to decay. The pions being made of quark antiquark pairs are very unstable. The charged pions are made of one up quark, and one anti down quark, or vise versa, and thus take a couple dozen nanoseconds to decay. The neutral

pions on the other hand, are made of a quark antiquark pair of the same quark flavor, and so annhililate almost immidiately. Muons which weigh around 105 MeV, go next, after a couple microseconds. The universe continues to expand and cool.

And finally we reach the 100 microsecond mark in the history of the universe. If we were to take a census of all the particles in the universe as of now, there are 52.5 billion neutrinos, 20 billion photons, 17.5 billion electrons, 17.5 billion positrons, and finally 8 protons and 8 neutrons. There is also an excess of 8 electrons, that meet the requirement of the universe being electrically neutral. Like the W and Z bosons, the charged and neutral pions, act as short ranged force carriers. Since the pions are hundreds of times lighter than the electroweak bosons, they carry the residual nuclear force out to a 2.5 femtometers of distance, which is around three nucleons wide. However, it is still way too hot for the first nuclei to form. Yet. The universe continues to expand and cool.

The formation of primordial black holes creates our material universe

Once the quark gluon plasma has transitioned to a baryon meson gas, there was much more annihilation going on than ever before. And as we know, this leads to the formation of black holes. Since the observable part of the universe extends for about 2 miles, or 3 kilometers, means that the black holes that formed have that size, with a mass of about our home star, the sun, in the modern universe. But back in this moment when the plethora of Kaons, Lambdas, Omegas, all annhililated, there was so much turbulence, that not only did huge solar mass black holes form, but because of the massive amount of heat generated by the annihilations, pockets of the baryon meson gas, surrounding newly formed primordial black holes, returned back to the quark gluon plasma that existed prior. The universe continues to expand and cool.

When this plasma returns to the hadronic state once more, it triggers more annhililations, and thus more black holes. This feedback loop created the bulk of black holes that will ever exist! We call this substratum of primordial stellar mass black holes, dark matter, which as the modern universe matures, will form galaxies, stars, the whole shebang. But back in the first instants of creation, none of this structure exists, except for the matter particles that will form it. Right now the total abundance went from one in quadrillions of extra matter to one in a few billion of extra matter particles. The universe continues to expand and cool.

That is like saying we had a tiny amount, now we have a surplus of extra protons and neutrons, that will be enough to form the entire material budget of existence. Of the mass of dark matter to baryonic matter, 84% is invisible primodial black holes, and 16% is the thin excess of protons and neutrons! This will be slightly modified in a few hours to a few days from creation, but here is the dominant source. The universe continues to expand and cool.

From here on out, the black holes spread out as the universe expands, some black holes merge, releasing gravitational waves, but as the dominant form of matter has now arrived, the question is no longer, about what the imbalance is, but what will happen to this thin excess of baryons created in this apocalypse. The universe continues to expand and cool.

The matter antimatter annihilation

But going back to a fraction of a thousandth of a second since the beginning, for every proton or neutron created in this cosmic game of pinball, billions of photons, of gamma-ray light, were also created! The universe was dominated by energy, and yet again, what I referred to as a thin excess will amount to all of the matter in our universe that will ever exist! Along with the billions of gamma rays, there also exist billions of electrons and antimatter electrons, also known as positrons. The temperature is still too high for electron-positron pairs to begin annihilating, and they remain in flux. The universe continues to expand and cool.

Now we reach the 1 millisecond mark. The temperature is in the tens of MeV. Electrons and positrons also known as antielectrons, even the sea of photons and neutrinos, continue to bash into the few isolated protons and neutrons, turning them into one another. This happens due to the weak nuclear force that acts at a scale 100 times smaller than a proton or neutron. When an electron gets near an up quark inside a proton, of which the quark has an electric charge of +2/3. If it is close enough, the up quark will transmute into a down quark, with a charge of -1/3. The proton has turned into a neutron. If this neutron hits a positron, it will convert back into a proton. The massless neutrinos, that act exclusively with the short ranged weak force, also have the ability to convert protons and neutrons into eachother. So at this point in time, protons and neutrons are always converting back and forth. So at first, the firestorm of mostly gamma radiation and electron-positron pairs, contains an equal number of protons and neutrons. The universe continues to expand and cool.

However the neutron is only 780 keV heavier than a proton, and the electrons weigh in at a tiny 511 keV. So as the temperature drops to a few MeV, it becomes much easier to make protons than to make neutrons in these conversions, and so there are fewer and fewer neutrons around as compared to protons. Over the next second or so, electrons and positrons are also starting to go through the same annihilation, that the quarks went through right at the start of creation. Then, as we pass the 1.8 second mark, the electron positron pairs begin annhililating, and over the next few hours, the concept of antimatter will become a distant memory. But now, with a universe 3 seconds old, some lower energy electrons and positrons still exist. The universe continues to expand and cool.

Also around this time, the neutrinos have not annhililated with their antineutrinos, because of their almost massless nature. Yet, as the universe continues expanding as it

always does, the neutrinos and antineutrinos are having great difficulty turning protons and neutrons into one another. This is because of the extremely short range of the weak force. When this process begins, the ratio of number of neutrons to number of protons, was dropping dramatically for a few seconds. The universe continues to expand and cool.

So now that neutrinos cannot change the number of protons or neutrons, the declining neutron number then settles at a value of 3 neutrons per 13 protons. Yet, neutrons are ever so slightly heavier than protons, and should decay. As of now the lifetime of a neutron is around 880 seconds, which is too far into the future as of now. The universe continues to expand and cool.

One thing to note is that when the majority of neutrinos stopped interconverting the protons and neutrons, there were still quite a few higher energy neutrinos in the distribution, still in equilibrium with the remaining electrons, positrons, and photons. This means that for a few more seconds, these neutrino outliers are still interconverting the protons and neutrons between one another, so while the number 3 neutrons per 13 protons seems like it should be taken at face value, it isn't set in stone. It is a complicated mixture of particles that interacts based on the temperature and concentration of a given sub-species of particles after decoupling. This is the way things are for most gradual proccesses. However after 10 seconds, this cosmic neutrinos background will be essentially non-interacting with the rest of matter, except through complicated neutrino oscilations between their 3 types, electron neutrinos, muon neutrinos, and tau neutrinos, and through the gentle tug of gravity, which "sees" all forms of energy and momentum present, but not their structural content. The universe continues to expand and cool.

The formation of galactic black holes

After a second since everything began, more and more massive black holes have been forming. With a radius of over 1 light second, any black holes formed from here on out, will have masses of over a 100 thousand suns. Compare this to the first few microseconds, when black holes produced the dominant forms of matter in our universe, But since the universe has been expanding and cooling, the density of matter and radiation is too thin for more matter production, despite the fact that there are billions of electron positron pairs to yet annhililate. The universe continues to expand and cool.

So, black holes are still forming, just at a slower rate. However, they are not producing much matter at this point from the annhililating electrons and positrons. Trace to insignificant amounts were produced. At this point, the black holes are supermassive when they from. Supermassive's are the seeds for the later formation of galaxies. So to summarize galaxies required all three stages of primordial black holes to form. The universe continues to expand and cool.

Why? The dark matter that will hold the galaxies together into the cosmic web, is already forming, and being that it is the combined gravity of all black holes, microscopic,

stellar, and supermassive, without them structure wouldn't exist. Not to mention that stellar mass primordial black holes formed the excess of matter over antimatter, and now constitute the bulk of dark matter as of now. Even the supermassive's are what is needed to create the galaxies themselves. The universe continues to expand and cool.

So to summarize a galaxy is made of both dark matter and normal baryonic matter, that formed in the first microsecond, and needs the supermassives to spark them into life. Without any stage of matter or black hole formation, galaxy formation would be impossible! The universe continues to expand and cool.

As soon as the supermassive black holes have formed, all three stages of black holes begin interacting with one another through gravity. The gravitational waves produced from the mutual gravity of passing black holes stirs the plasma ever so slightly. Also the black holes are immune to the radiation pressure, so they're structure immediately roughens to form a cosmic scaffolding of purely black hole dark matter. The universe continues to expand and cool.

The nuclear fusion into alpha particles

One second passes, then five, then 20 seconds have elapsed. Then a minute passes. The residual nuclear force, is strong enough to bind the nucleons together, but this isn't happening at all. This is because when a proton and neutron collide and form a deuteron, a high energy photon will break the first nuclei right back down to the nucleons that already exist. But a deuteron has a binding energy of 2 MeV, so it should be stable enough to exist. Nope. Remember that there exist 20 billion photons. Even if the average temperature of this thermal radiation is on the order of 100 keV, or 0.1 MeV, there will still be a few outliers with energies over 2 MeV. Even if a few very high energy photons exist, its over for a deuteron. The universe continues to expand and cool.

Yet again, as always, the universe expands and cools. Also, neutrons decay, so given that we started with 3 neutrons at first, after 3 minutes, there are only 2 neutrons left, as one of the neutrons has beta decayed back to a proton, along with an electron and an antineutrino. We now have 20 billion gamma ray photons, along with 14 protons and 2 neutrons. Also, an excess of 14 electrons also exist, along with the hundreds of millions of electron-positron pairs that are under constant annhililation. The universe continues to expand and cool.

So this means that for the next four minutes or so, not much changes to the firestorm of gamma-rays and annihilating electron-positron pairs. A few of the many neutrons that still exist, have naturally decayed back into protons, so while the neutron to proton ratio used to be 1 in 5 a few minutes ago, right now its closer to 1 in 7. The average lifetime of a free neutron is 880 seconds, otherwise put, 14 minutes and 40 seconds. I should note that although the temperature is well high enough for fusion to occur, the sheer energy and number of gamma ray photons will shred down any nuclei

that try to form, so the universe, as of now, contains only free protons and free neutrons. The universe continues to expand and cool.

Then, right after the clock strikes 4 minutes and 20 seconds, does something dramatic happen: Nuclear fusion! Now, as the temperature decreases, there are less and less photons with energies of 2 MeV, and when the temperature, or average photon energy, drops below 78 keV, deuterons are stable, and the fusion process continues on. In other words, the intensity of gamma radiation is now low enough for the first nuclei to not be blown apart. Most nuclei that could form at this point, like tritons or helions, also have binding energies not much more than deuterons. However there is one special kind of nucleus, known as an alpha particle. It has a whopping binding energy of 28.3 MeV. That is to say 28,300 keV! The universe continues to expand and cool.

At this point the majority of the nucleon excess is in protons, alpha particles, and neutrons. But if one zooms out to get a larger sample size, not of 16 nucleons, but of 10 million nucleons, one finds out that not only do other nuclei form, but their abundance shows they act as intermediate steps from the conversion of single nucleons into alpha particles. Out of 10 million nucleons, the peak number of nuclei is the following: 5,041 deuterons, and 683 tritons. A deuteron consists of a bound state of one proton and one neutron. A triton consists of a bound state of one proton and two neutrons. After this peak in abundance, the deuterons and tritons get used up in the formation of more alpha particles. The universe continues to expand and cool.

An alpha particle consists of two protons and two neutrons. The stability of alpha particles, is extremely important in the near future of the nuclear reactions. Every proton and every neutron in existence are now smashing together to build alpha particles: Clusters of 2 and 2, that is to say, 2 neutrons with 2 protons. The universe is now 265 seconds, or 4 minutes and 25 seconds old. At this point, as soon as alpha particles form, it becomes extremely difficult to destroy them. All nuclei that contain any neutrons, including the soon to decay neutrons themselves eventually get locked up inside these alpha particles. The universe continues to expand and cool.

As the number of free neutrons declines to zero, the nuclear reactions which have been proceeding rapidly, radically changes its form. Out of 10 million nucleons total, the following abundances have occurred as follows: The number of deuterons drops from 5,041 deuterons to 264 deuterons. The number of helions grows from zero to 102 helions. A helion consists of a bound state of two protons and one neutron. Also, the number of tritons drops from 683 tritons to 1 triton nucleus. This it will remain for years to come. The universe continues to expand and cool.

For the next 10 seconds, the number of alpha particles, grows to a value of 1 alpha particle for every 12 protons. The story of alpha particles, is not over yet. As the clock reaches 4 minutes and 30 seconds, all of the neutrons get used up in the reaction, and the 10 seconds of nuclear fusion grinds to an immediate halt. Why so early? Even though fusion is still occurring in vast quantities, not much happens to the composition of the

nuclei. The 12 protons, and 1 alpha particle, are all smashing into one another. When such a collision takes place, it produces an unstable nucleus with 5 or 8 nucleons. Such a nucleus will undergo alpha decay, and revert right back to the same nuclei as before. The universe continues to expand and cool.

Also around this time, from 5 to 20 minutes after the big bang, there is still plenty of fusion occuring, but just because heavier elements are improbable doesn't mean they do not form. So to be fair, I will list out the trace nuclei that do form around this time. We talked about 12 protons and 1 alpha particle, that dominates the nuclear budget. Then we expanded our inventory from 16 nucleons up to 10 million, and found other nuclei, namely 264 deuterons, 102 helions, and 1 triton. Tritium has a lifetime of 12.32 years which is too far into the future as of now. But out of 1 quadrillion nucleons or 15 powers of ten less than hydrogen and helium totals to, there are the beryllium and lithium isotopes. In order of declining abundance, we have the unstable beryllium-7 nuclei with a lifetime of 53.22 days, that are currently decaying into lithium-7 nuclei. Currently Beryllium-7 is at an abundance of one nucleus in 500 million nuclei total. In the first 5 to 7 minutes after the beginning, the abundances of Lithium-7 peaked at 1 nucleus in 20 million nuclei total. But after 10 minutes, there was still plenty of nuclear reactions that destroyed Lithium-7 so it dropped to a value of 1 nucleus in 3 billion nuclei total, with Beryllium-7 now in the lead of trace isotopes. Then there is Lithium-6, with an abundance of 1 nucleus in 1 trillion nuclei total, making it the rarest of trace isotopes. The content of the nuclei are the following: Beryllium-7 has 4 protons and 3 neutrons, Lithium-7 has 3 protons and 4 neutrons, and Lithium-6 has 3 protons and 3 neutrons. All of these trace nuclei are easy to destroy and hard to make, hence the very low abundances. The universe continues to expand and cool.

Strangely however, free neutrons, which were common before the universe was 4 minutes old, are now not completely gone! Yes it is true that the alpha particles contain neutrons, so when that majority forms and stabilizes, the number of free neutrons declined rapidly. But now, 5 to 20 minutes after creation, the neutron number doesn't quite settle, not because of nuclear reactions, but because all neutrons have an average lifetime of 880 seconds which is 14 minutes and 40 seconds. So although not zero, it is still dropping. At 8 minutes, there is one free neutron per 35 million nuclei total. So while protons and alpha particles domainate the nuclear matter budget, neutrons are one of the trace nuclei, but are extremely radioactive and after 1 hour or so, will be essentially all gone, converted back to stay as protons one last time. The universe continues to expand and cool.

After some more time for the universe to expand and cool, the universe ages past the 20 minute mark. However, these stable nuclei are positively charged, and like charges repel. This means that there is an electric potential barrier right beyond the reach of the residual nuclear force. As the nuclei slow down, there is less and less kinetic energy available, and by the end of the first hour of the universe, almost every

nucleus avoids every other nucleus around it. The ever expanding and cooling universe now has a chemical formula of 12 protons, 1 alpha particle, which goes along with an excess of 14 electrons over millions of electron-positron pairs, and also the 22 billion photons of gamma-ray light. The universe continues to expand and cool. The fusion process halts completely, as the 12 protons, and 1 alpha particle, not only fail to create new nuclei, but at this point they don't touch eachother in the first place. The nuclei just avoid eachother from now on. The universe continues to expand and cool.

In the background, the invisible intangible radiation of the 18 billion neutrinos has been existing alongside the 22 billion gamma ray photons. Since neutrinos decoupled within the first second of existence, they've been hardly interacting with anything. But that doesn't mean they do not exist. As electron-positron pairs annhililate away into photons, this increases the photon temperature, but not the neutrino temperature. And since everything coupled to the photon temperature as of now, its useful to ignore the lower but original neutrino temperature. If you must know, compared to a photon temperature of 1, the neutrino temperature is the cube root of 4/11. The universe continues to expand and cool.

Mentioning the average temperature is fine if everything were in perfect thermal equalibrium. Almost so, but the fusion of protons and neutrons into alpha particles produced plenty of high energy gamma rays, on the order of 1 to 10 MeV. Since fusion has already occurred and halted, the average mjority photon temperature is much lower. It will take a long time for these high energy photons to equilibriate with the other photons to reform the perfect thermal distribution. Compared to neutrinos in the first seconds, they also have high energy outliers, but neutrinos don't interact with matter, so those outliers still exist, stretched out by the expansion of space itself. But we should expect that after a few months the equilibrium of photons, which do interact with matter such as electrons and nuclei, will eventually equilibriate once again. The universe continues to expand and cool.

Hours into the creation of the universe, the last few dozen electron-positron pairs finally annihilate away into even more photons of gamma-ray light. The particle count is now, 12 protons, 1 alpha particle, 14 electrons, and 22 billion photons. This it will remain for almost an eternity. As a sense of comparison, a proton weighs as much as 1,836 electrons, and an alpha particle weighs as much as 7,294 electrons. The universe continues to expand and cool.

The black holes arrange into a cosmic web

At this point, we are hours into the formation of everything. No more annhilations are happening. By remembering that the universe is radiation dominated, means a few things. First, there are no more black holes that are to form any more. The past annhililations were purely thermal in nature, and are classified as radiation. With only the ghostly neutrinos and the photons of gamma ray and X ray light dominating the

energy budget for radiation, no annhililations are occuring, and as such the formation of primordial black holes has stopped. The universe continues to expand and cool.

The second effect of the radiation dominating, is that its pressure holds up normal baryonic matter from collasping under it's own gravity. And also, it's the photons of light doing the work of keeping the turbulence down to a minimum, as the neutrinos hardly interact with anything. From now on, this primordial plasma, of protons, alpha particles, electrons, and photons, are all scattering off one another hard enough to keep the plasma uniform to 1 part in 100 thousand. This it will remain for a very long time. The universe continues to expand and cool.

However, the primordial black holes that already exist don't follow this same logic. They continue to suck in everything nearby, including other black holes. Even though no new black holes have formed, the 84% of dark matter continue to exist. With the other 16% of normal matter locked up with the radiation, it is this 84% that will build the cosmic web. So although, primordial black holes and normal matter seem to be running the show, weight for weight, its the radiation energy that has dominated and will continue to domninate for a very long time, possibly for the next few to dozen millennia into the future. The universe continues to expand and cool.

But that doesn't stop the primordial black holes from pulling on one another by their own self gravity. Black holes orbit and merge, releasing gravitational waves. Soon, we have a cosmic web of dark matter, that although insignificant at this moment, will play a key role later on in the history of everything. The universe continues to expand and cool.

Remember those trace nuclei, like beryllium-7, lithium-7, lithium-6, and so on. They are easy to destroy. These primordial black holes also had a huge impact on the destruction of these low binding energy nuclei. Unlike the alpha particle which is a nuclear brick. The trace nuclei are like nuclear fluff. So when this radioactive nuclear mixture nears a black hole, the black holes also grow from consuming anything that cross their event horzons: all forms of radiation, all forms of matter, even other black holes. This heats the surrounding matter up in the immidiate vicinity of their accretion disks. This heat then destroys many trace nuclei in the region. This is why the total number of all trace nuclei are dropping. It isn't radioactivity. Only neutrons, which are non-existent, Beryllium-7 which is next to go, and Tritium which is to go after that. But radioactivity is passive, it is disctinct from the active fission of nuclei by high energy photons of radiation. So depending on the stability, and closeness to these hot spots, many nuclei are disintregated. This changes the abundaces of many trace isotopes in the early universe. But as time marches on, most of the accretion dies down, due to matter and radiation thinning out. The universe continues to expand and cool.

Also these hot spots are creating even more high energy photons, that while many disintegrate nuclei, the scattered light still has much to high energy, so along with the nuclear reactions that occurred from 3 to 20 minutes after the big bang, the combined

effect is to make it very difficult for the photons to reach equilibrium again. But as time passes, the universe expands. The expansion of space stretches all the field quanta out, and this lowers the temperature of the universe, coupled or uncoupled. With all this time on our hands, the black holes have spread out enough to make the photons begin to reach equilibrium. But the completion of this proccess into pure random heat will take many months. The universe continues to expand and cool.

The primordial plasma clears up

This whole time, electrons and photons, pinball one another. The scattering of, electrons and photons, is fully described by the theory of QED. QED begins with the spacetime of special relativity. This spacetime is described by the O(3,1) group. The particles of QED, are representations of this symmetry group. Electrons are massive charged spinors. Photons are massless neutral vectors. Put together, they interact via a minimally coupled U(1) internal symmetry group. As of now, QED was not the main player in the history of the universe, as it was unified with other internal symmetries, into the SU(5) group. The universe continues to expand and cool.

However, now that the nuclear reactions have stopped, QED is what is left over. The electrons and photons form a plasma known as the cosmic soup. In it, electrons are known as cathode rays, and photons are known as X rays. The chemistry of the universe is pretty much constant after the first few hours have elapsed. The cosmic soup clocks in at a temperature of 1 keV. Otherwise put, 11.6 million degrees kelvin, and dropping. In fact, it's still too hot for anything tangible to exist at all. The universe continues to expand and cool.

A day passes, then a week goes on by. The only thing that changes is the expansion of the universe. Nothing has happened to the plasma. Even after a whole month of this expanding and cooling, the temperature, pressure, and density, are all surely dropping, yet nothing else has happened to the cosmic soup. Why? As compared to the nuclei, which are femtometers in size, and weigh in at many GeV, electrons are nothing in comparison. Even the photons that carry the electromagnetic force, is 137 times weaker than the other forces. So not only do the electrons need to slow down, they need to be captured by the nuclei, for the first atoms to form. The universe continues to expand and cool.

Every electron, cannot be crammed into a volume smaller than 386 femtometers, without producing antimatter. This is assumming that the cathode rays are moving near light speed. But, at this day and age, the cathode rays have much longer wavelengths than this, since they're moving much slower than light speed. The math of QED, says that the electrons must be moving 137 times slower than light speed for them to be captured. With the electrons so spread out compared to the nuclei already, the cathode rays must have wavelengths hundreds of thousands of times longer than the nuclei are big. And that is a big problem. The universe continues to expand and cool.

As weeks pass by, something is happening to the rarest of trace nuclei, as the beryllium-7 nuclei with a lifetime of 53.22 days are gradually decaying into lithium-7 nuclei, increasing the number close, but not quite to the value it had when the universe was only 5 minutes old. All of this is only significant at scales with an gigantic sample size of over 1 billion nuclei total. But in the grand scheme of things, nothing has changed to the chemistry of the uniform cosmic ocean of fire. The universe continues of expand and cool.

As months turn into years, then into decades, the gamma ray photons have stretched out so much, they are now X-ray photons. As the firestorm of a universe continues to expand and cool, not much happens for a very long time. The universe as a firestorm that is uniformly spread and infinite in extent, continues to expand and cool. However, if one looks at our huge sample size of 10 million baryons, something did just happen. Our last triton nucleus has beta decayed into one more helion nucleus. So while 102 helions used to exist, the extra helion added in, gives us 103 helions. This is the last time a beta decay happens for a very long time. The neutron inside the triton nucleus took 12.32 years to decay, compared to a free neutron decaying in 880 seconds, its an eternity. The universe continues to expand and cool.

After all of this radioactivity, nuclear fusion, black hole production and growth, the photons of light are slightly off equilibrium, and now the universe has produced enough of a disturbance of one part in 100 thousand. Now after many years, the composition and energy distribution of the matter and radiation has reached equilibrium once more. But instead of this heating just spreading out, it rings like a bell, or better yet, like an expanding balloon, vibrating once every few years or so. The universe continues to expand and cool.

Decades pass by, then centuries, and eventually millennia pass by in the hundreds. The universe is so much more diluted now that its self gravity, which is slowing down the expansion of the universe, takes more time to expand by the same amount as usual. Up to this point, the temperature-time relation has been following an inverse square root curve. At one second the temperature was 1.27 MeV, so at 100 seconds or 1 minute, 40 seconds, the temperature drops ten fold to 127 keV. To arrive at the temperature we take the time to an exponent of negative one half. This pattern is about to break, as the exponent will shift to a value of negative two thirds. If the temperature in the near future of 100 thousand years is 620 meV, then if we project out to 1,000 times into the future of 100 million years, the temperature will drop a hundred fold to 6.2 meV. This is because matter will soon be dominating the expansion history of the universe. The universe continues to expand and cool.

By matter I mean all forms of mass including not just nuclei and electrons, but also primordial black holes that outweigh all of our baryons by a factor of 5. But that is for a later chapter. For now also realize that its not just the photons that constitute radiation, but also the ghostly neutrinos. If we just looked at the total energy budget of

the universe, around this time the temperature has finally dropped so low to the point that our small excess of matter over antimatter now dominates its gravitational evolution. The universe continues to expand and cool.

Moreover, all of the photons of X-ray light, have stretched out into photons of Ultraviolet light. However, as the universe expands, a new problem surfaces. Billions of photons might have an average energy of 5 eV or 58 thousand degrees kelvin, yet the truth is that as always there are high energy outliers. Some photons have huge energies well over 269.3 eV and as such we will have to wait until these high energy photons are gone until atoms can fully form. The universe continues to expand and cool.

Out of the total of 10 million nucleons the following happens: As the universe expands and cools below 16 thousand degrees, each and every of the 625,000 alpha particles captures an electron forming 625,000 helium-4 ions. Of the far and few between helions, each of the 103 helion nuclei also capture an electron, forming 103 helium-3 ions. The universe continues to expand and cool.

Next, as the universe expands and cools below 7 thousand degrees, each and every of the 625,000 helium-4 ions capture another electron, this time forming 625,000 helium-4 atoms. Again, the same thing occurs for 103 helium-3 ions, as they too capture their second electrons, forming 103 helium-3 atoms. The universe continues to expand and cool.

Then, as the universe expands and cools below 4 thousand degrees, each and every of the 7,500,000 protons captures an electron, forming 7,500,000 hydrogen-1 atoms. Of the far and few between deuterons, each of the 264 deuteron nuclei also each capture an electron, forming 264 hydrogen-2 atoms. The universe continues to expand and cool.

After that, as the universe expands and cools below 3 thousand degrees, the number of free protons and free electrons have not fully recombined into hydrogen-1 atoms. Instead, 578 of the 7.5 million free protons and with them 578 free electrons also remain. The last 578 free electrons have for the first time in history, stopped scattering light, leaving the now visible light photons to begin streaming freely throughout the cosmos. Let There Be Light!

The cosmic dark ages

The universe continues to expand and cool. 377 millennia have elapsed since the beginning, and is flooded with atomic hydrogen-1 and atomic helium-4. The color temperature of the radiation is pushing 3 thousand degrees Kelvin, but is gradually dropping as we speak. Of the 10 million nucleon total. We have the following abundances for baryonic matter: 7.5 million hydrogen-1 atoms, 625 thousand helium-4 atoms, 578 free protons, 578 free electrons, 264 hydrogen-2 atoms, 103 helium-3 atoms. However it remains to be seen what kinds of chemistry will occur in this white hot, near vacuum atmosphere. The universe continues to expand and cool.

From 3,000 degrees kelvin, or roughly 5,000 degrees Fahrenheit, the radiation temperature and matter temperature though decoupled, are dropping in tandem as we speak. As the temperature drops below 1,150 degrees kelvin, or 1,610 degrees Fahrenheit, of the 10 million nucleon total, 4 hydrogen-1 atoms stick together in pairs, forming 2 hydrogen-1 molecules. The catalyst here is the rare but intermediate formation of the hydrogen molecular cation, formed of two protons held together by a single electron. It's the result of the collision between a hydrogen-1 atom, with a free proton. The universe continues to expand and cool.

Then, as the radiation temperature drops below 530 degrees kelvin, or a relatively hot 490 degrees Fahrenheit, the matter temperature begins cooling twice as fast. Instead of the radiation temperature which as a time-temperature exponent of negative two thirds, the matter temperature now has a time-temperature exponent of negative four thirds, which means that if the radiation temperature drops from 530 kelvin to a bone cold 53 kelvin, the matter temperature will have dropped to 5.3 kelvin above absolute zero, twice as cold as the radiation temperature has dropped. The universe continues to expand and cool.

Next, as the radiation temperature drops below 300 degrees kelvin, or a luke warm 80 degrees Fahrenheit, another 34 hydrogen-1 atoms have stuck together in pairs, forming an additional 17 hydrogen-1 molecules, making a total of 19 hydrogen-1 molecules. This time the catalyst here is different. It is the rare but intermediate formation of the hydrogen anion, formed of a single proton holding two electrons. This time, it is the result of the collision between a hydrogen-1 atom, with a free electron. The universe continues to expand and cool.

The 19 hydrogen-1 molecules are all each formed of two protons held together by two electrons. Below room temperature, the following census holds in detail: 7,500,000 hydrogen-1 atoms, 625,000 helium-4 atoms, 578 free protons, 578 free electrons, 264 hydrogen-2 atoms, 103 helium-3 atoms, and our 19 hydrogen-1 molecules. The universe continues to expand and cool.

So far, we have been talking about only a small fraction of what matter and energy exists out there. It is like saying we have a jar filled with 100 grams of gas. As we know from earlier, 75 grams would be atomic hydrogen-1, and 25 grams would be atomic helium-4. The truth that has been overlooked is this conundrum: An additional 530 grams of invisible intangible matter also exists.

This form of matter consists of countless primordial black holes. A black hole is a region of space with a gravitational pull that is so strong that not even light, the fastest thing in the universe, cannot escape from its deadly grip. This is an extremely important concept: All fundamental particles are rotating black holes with the same mass and same spin as the wave they constitute. This means that all black holes are fundamental waves too in the same sense as of any other wave, such as the electrons of electricity and the photons of light are all fundamental waves. This means that we should widen our search

for extremely exotic wave types that hardly interact with anything. These primordial black holes will be a fundamental turning point in the evolution of what follows.

The fate of the universe rests on the unification of physical law. There are three main sets of new phenomena, that were incorporated into the three pillars of modern science. The three pillars are: universal gravitation, special relativity, and quantum mechanics. The associated physics reduces to our common sense, by making a series of approximations. So even though our common sense worldview works well in the everyday, in the grand scheme of things, our universe is stranger than fiction.

With this in mind, a black hole is simply a natural consequence of these three main concepts of physics. In a sense, every black hole is just as fundamental as every other particle of matter and light that exists. In fact, the only difference is their mass and spin. Therefore, all rotating black holes are just as "real" as anything else that exists. Lets see what has happened to this mysterious form of matter, so that we can continue our story of everything!

All of these black holes have been colliding and merging, since the beginning, forming a sprawling network of black holes, called the cosmic web. The cosmic web is truly massive. But the reason I bring this up now is because, before the universe was 377 thousand years old, the radiation pressure was holding up the ordinary matter from gravitational collapse. But now, going back to when the light has been set free, there is no more radiation pressure to prevent collapse, and collapse it goes. The universe continues to expand and cool.

As the universe expands and cools, over the next few million years, the color temperature dropped from white, to pale yellow, to vivid orange, to cherry red, and finally fades into the near infrared. If we were somehow around back then, we could feel these rays as radiant heat, although there would be nothing to see. Just a uniform still darkness all around. The universe continues to expand and cool.

As for the matter, the gas is no longer uniform, and as the contrast increases, the gravity of both the black holes and the atoms of hydrogen and helium, becomes unstoppable. In just a few hundred million years, the cosmic web of gas starts resembling the cosmic web of black holes. This is like the scaffolding of a building. The black holes are the scaffolding, and the gas of normal matter is following the same pattern. The universe continues to expand and cool.

As this new consolidated cosmic web continues to expand and grow, the scene will soon change dramatically to include new structures never seen before! The cosmos is still cold and darkness envelops the night sky. But a chain of events will form a hierarchy of scale, where everything will eventually depend on everything else. The universe continues to expand and cool.

But before the sky lights up, the darkness has one last secret. Of the rarest nuclei that exist, atoms of lithium stick together in rows and columns to form dust grains, and are very rare. Each atom is one in trillions now, but the last time we counted

the census it was rounded to 1 part in 16, 1 part in 10 million, and 1 part in a quadrillion. Within this last quadrillionth of matter, rare isotopes like carbon, nitrogen, oxygen, and many others, have been created in the first hour, but are so rare to not contribute a signifcant difference. Could it be that life on earth arose, because there was a random surplus of these nuclei? Everywhere else, there must have been negligible amounts, and as such we will only find life where the materials will be concentrated. This will soon change as the first stars form, within galaxies: Places that stars live out their lives and die. The universe continues to expand and cool.

The formation and evolution of cosmic structure

As the cosmic web continues to expand and grow, the first irregular galaxies form along the filaments of the cosmic web. Just like dew drops on a spider's silk, each of these galaxies is a loose collection of stars, gas, dust. As time marches on in the billions of years, the irregular galaxies merge into larger irregular galaxies. As it turns out, the densest regions of the cosmic web are where the irregular galaxies form. But since the cosmic web grows, the galaxies are carried along with the filaments of the invisible matter that consitutes most of the cosmic web. Whenever the filaments of the cosmic web lock together, is when most galaxies cluster and merge.

Zooming inside one of these irregular galaxies, there is plenty of gas from the big bang, and along with the dust from previous supernovae explosions, creates a cloud of diffuse gas known as nebula. The nebula fragments into a few collapsing clouds, which in turn forms the next generation of high mass stars: Blue main sequence stars. 10 solar masses, and their surfaces burn brightly as 20 thousand degrees in the ultraviolet, as a sky blue color. The nuclear fusion has restarted once again, this time within the cores of stars!

After another brief 100 million years later, after its formation, the blue main sequence star, runs out of its initial supply of nuclear fuel. It expands from a radius of 5 suns to 530 suns. Its surface temperature drops to 4000 degrees, or about that color of incandescent white light bulb. It is now an orange supergiant star, with its core temperature skyrocketing, inside, it has onion shells of fusing elements and isotopes. It lasts for only another 10 million years.

Every massive orange supergiant star explodes as a type II supernova! This star is no exception. The core has fused its last supply of elements into Iron-56, the most stable nucleus that exists. The core implodes in fractions of a second, into a neutron star remnant. The resulting conversion of nuclei into pure neutrons relases plenty of energy, that ricochets the rest of the stellar matter, creating a massive shockwave that blows it up. The energy from such an explosion outshines the rest of its galaxy for weeks, if not months. The explosion leaves behind a neutron star, which is a dead stellar core of compact neutron matter.

The resulting elements from type II supernovae contains: 23 carbon-12 nuclei, 5 nitrogen-14 nuclei, 156 oxygen-16 nuclei, 14 neon-20 nuclei, 2 neon-22 nuclei, 6 magnesium-24 nuclei, 4 silicon-28 nuclei, 2 sulfur-32 nuclei, and 2 iron-56 nuclei. Massive star explosion, after massive star explosion, the galaxies are being seeded with the elements needed for life itself. Elements like oxygen, which when combined with hydrogen from the big bang, forms lots and lots of water, the universal solvent. The gases and dust grains disperse into the interstellar medium.

A neutron star remnant is a very amazing object. A dense quantum object made of a plasma of only neutrons. However the neutrons are as compact as they can be. This is the same force that prevents solid matter from passing through itself, but here, it applies to the whole neutron star remnant at once: An atomic nucleus as massive as a star. For some facts, a neutron star remnant, has the mass of up to 3 suns, and a radius of a large city.

We zoom back out to the intergalactic scale. A few billion years have elapsed since the first irregular galaxies formed. As the invisible matter of the cosmic web locks together, two sheets of this invisible matter, with each sheet being a network containing more than a few dozen irregular galaxies, merge together. What was two galaxy clusters is now a grouping of a few larger galactic mergers. Gas, stars, dust, are all flung in all directions. Gravity brings the matter back together into three large spiral disk galaxies, which in turn ignites more stars within these new spiral galaxies. This creates their spiral arms and pinwheel character. In the mean time, the invisible cosmic web has grown so much by now, that what was a network of irregular galaxies is now three huge hubs of the invisible matter, inside each a spiral galaxy. It is as if a cosmic dance is taking place, with the skaters replaced by huge incandescent galaxies. The three new spiral galaxies continue to absorb more and more irregular galaxies into their spiral arms. This slightly disrupts their spiral arms, but after another few billion years, each of these spiral galaxies has grown considerably, now as three grand pinwheels.

Zooming inside one of these spiral galaxies, there is still lots of gas from the big bang, and along with even more of the dust from previous supernovae explosions, which creates several more clouds of diffuse gases that we know as nebulae. These nebulae fragment more, and due to extra turbulence from supernova explosions in nearby spiral arms, they collapse and fragment further into a few hundred collapsing clouds, which in turn forms the next generation of intermediate mass stars. One of these stars is the sun! 4.6 billion years ago! Our sun and all the others in the loosely bound cluster, known as an open star cluster, burn with a surface temperature of 6 thousand degrees, which looks more or less, like white daylight. The open star cluster disapates its sun-like stars into the disk of the spiral galaxy that birthed them. Nuclear fusion has it's torch passed down to the next generation of stars! For more detail for this particular star, please see what follows from this moment onwards, something unlike anything else in our universe so far…

A new star forms, one that will possess something not seen in the story of everything so far… A star forms that will later be called: The Sun! The cloud of matter surrounding the newborn sun flattens into a disk. Clouds of water, methane, and ammonia, exist along with an atmosphere of gasses such as carbon dioxide and nitrogen. Huge bolts of lightning vaporize the dust grains into minerals such as graphite, quartz, olivine, and iron. Around the sun, asteroids and comets form and smash together haphazardly. A rock forms from the orbiting debris, one large enough to draw in other asteroids from a distance by its own self gravity. Rocks smash to bits, but the gravity it causes is too much, and asteroids snowball together into a ball 8000 miles wide!

The impressive amount of heat created from these impacts has liquefied the whole material of the world. The denser liquid iron, sinks to form the earth's core, and the molten rocks containing silicate minerals like quartz and olivine, float above the liquid iron core. Hundreds of these baby worlds form, most orbiting the sun. Farther out, ice clouds have condensed, forming the seeds for thousands of more baby ice worlds, also orbiting the sun. These worlds smash into one another.

When all of the worlds, with their physics of being fluids and reacting to their self-gravity, all settles down. What remains is a system of 1 star, the sun, 8 planets, 19 moons, and plenty of other debris that didn't form into anything substantial. The universe is a mess, and sometimes, its the messy things that are interesting. But 4.5 billion years ago, the solar system has a few hundred full sized planets and moons. The first five are, Mercury, Venus, Earth, Mars, and the last is Theia! All lava worlds, with liquid iron cores.

After millions of years pass by, their orbits shift and vary, and Theia comes careening into the inner solar system. Theia smashes into the earth, like a planetary kid smashing an oil puddle on a rainy day! The impact ejecta, form a cloud of molten debris that reforms into a couple if not more baby worlds. After a closest approach to the re-melted earth, does our moon form. In the outer solar system, similar processes form Jupiter, with its 4 large moons: Io, Europa, Ganymede, and Callisto. Saturn, with its large moon Titan. Uranus. Neptune, and its moon Triton. And so on, with baby worlds cooling off into the shadows of the solar system's kuiper belt. Pluto and Eris are two examples.

The mess settles down, with comets raining down into the inner solar system again. These comets contain plenty of water, amino acids, fatty acids, and minerals. Though not exactly edible, they are the building blocks of all forms of life that will soon form. Now, it is here that things get really interesting. Living cells, are at a most fundamental level, are chemical reactions, dissolved in a liquid, with a boundary. For a man made car, it is Gasoline, Oxygen, and Heat, reacting in an internal combustion engine, that propels the gears and the wheels forward. For a living bacterium such as this, it is similar.

Cyanobacteria have a Metabolism, reacting Carbon Dioxide and Water, into Glucose and Oxygen, using Sunlight as a concentrated energy source. The similarity is there for a reason, as, coal, oil, and natural gas, are the result of plants and

cyanobacteria, taking in sunlight. By burning these fossil fuels, we release it back into the atmosphere.

A similar reversal of energy takes place here: Deep beneath the newly formed exotic oceans of planet earth. A molten hell, cooled down to form a solid crust of Basalt rock. In these oceans, chemicals of all kinds, combined in all sorts of exotic combinations. It took countless tries, but once nature found the key to a succesful cell. The cells that made it passed on those genes for survival, and the ones that didn't, just didn't. This is chemical reactions turned into biological evolution within seconds.

Hot magma oozes up through cracks in the earth's crust known as serpentization. From this the acidic ocean water, meets alkaline water from the volcanic vents. The first cell forms in one of these environments, and the proteins become enzymes, like helicase, transcription factors, ribosomes, and kineticores. The cell divides and this is what guarantees its survival.

Billions of years later, cyanobacteria evolve from these microbes, and change everything! Oxygen poisons most microbes, and evolution speeds up. It burns away the carbon dioxide and methane produced from volcanoes, throwing earth's surface into a deep freeze. The oxygen reacts with the green dissolved iron in the oceans, creating rust, or otherwise put, iron ore, that settles to the ocean floor. With this mix up, continents form from volcanic islands, Granite becomes a dominant rock, instead of Basalt. Moreover, oxygen levels rise further in the atmosphere, together with the rise of first plants.

540 million years ago, life becomes unstoppable! From microbe to eukaryotic cell. From cell to colony, we adopted our respiration and metabolism. Then, from a worm, we evolved into a fish, and dodged extinction of a nearby gamma-ray burst from a supernova. The sea scorpions, and some horse shoe crabs went extinct. The supercontinent Pangaea forms from Gondwana, a continent near the south pole. But life doesn't stop there… The suns ultraviolet layer reacts with atmospheric oxygen, forming the ozone layer. Plants and animals crawl into land. A swamp full of gigantic spiders and insects, then becomes a paradise of reptiles. Oxygen levels slowly decrease slightly to 21%.

By 250 million years ago, 95% of all species die, from basaltic volcanic flood eruptions in what will be Siberia Russia. After the apocalypse, Dinosaurs reigned supreme for then on. Pangaea broke up forming the Atlantic ocean, separating Africa, Europe, and Asia, from the Americas. Small mammals, evolved that were the perfect snack for the dinosaurs.

Then 65 million years ago, a random asteroid smashes into the Yucatan peninsula of Mexico. With the dinosaurs gone, many birds and mammals still remain. The mammals diversify immensely. Whales, Bears, Horses, Tigers, Wolfs, and you guessed it? Primates! In the last 2 million years, humans evolved further into people that can think, work together, and communicate, hunt and farm, build cities, and finally invent science. This is

us, we are here! We are stardust that figured it all out…

But, if the theory of everything predicts our existence, did life form anywhere else, and if so, what are they like? We are the children of the stars, we are, atom by atom, cell by cell, person by person, the stuff of stars… Hydrogen from the big bang, Oxygen, Carbon, Nitrogen, all from massive stellar explosions, polluted the pristine gases of the big bang with heavy nuclei. Moreover the atoms from one hand likely came from a different star than the atoms of your other hand. We are litterally stardust… In a sense, our consious awareness of this adds another layer of complexity to the problem. We are not a drop in an ocean, but the whole ocean in a single drop. Think of it this way? The universe may be vast if not infinite, but it's not size that matters but complexity. Starstuff that became aware of itself. And since we are the universe in human form, the universe is consious, through our mere existence. So enjoy existence while it lasts, because reality is a dangerous place. And moreover, what better thing to enjoy than to figure out exactly that.

After this, the story of human life is not over. We spread out to the whole galaxy in a cosmic blink of the eye. Then with our advanced technology, we settled down into new distant worlds. Within ten thousand years, humanity has went from a hunter-gatherer society, to conquering much of our galaxy. Wars take place on some worlds. Scientific discovery takes place on others. On some, humanity finds a way to live. Over the next million to a billion years, we all look home to the world that made us.

But that world, Planet Earth, is about to be destroyed. Over the next two billion years since, wildfires burn all forests down completely as the oceans have completely evaporated, killing all non-human life in the process. Then the sun slowly begins reclaiming its own creation. Earth life is over, but the rest of the universe is still out for humans to explore. Who knows what will become of us as we continue on to other galaxies.

We eventually deplete our resources, and all of humanity, planet by planet, moon by moon, every substation throughout the universe, goes through panic, then famine, war, disease, and finally death. Humans are extinct. But their machines they left behind still operate for another few centuries. After that no trace of life exists anywhere ever again.

Now, 10 billion years after the formation of our home star, our sun expands to 60 times its original radius. This red giant star, and has a surface temperature of 3000 degrees, about that color of an older incandescent light bulb. The sun's core has begun to fuse its helium-4 ash into carbon-12 and oxygen-16. This bloated angry red giant star, lasts for another 1 billion years, until it's core becomes dangerously unstable. The core gets denser and energy waves from it, expelling plenty of stellar matter away from the diffusing red giant star into what is known as a planetary nebula. After a few thousand years later, what is left over is a very dense dead stellar core of compact atomic matter known as a white dwarf.

The resulting planetary nebula contains: 69 carbon-12 nuclei, and 12 nitrogen-14 nuclei. Like the other supernovae explosions, the planetary nebulae from countless red giant stars seed the galaxies with even more matter, necessary for life, which includes a plenty surplus of carbon. The gases and dust grains disperse into the interstellar medium.

A white dwarf remnant is a quite amazing object. A dense quantum object made of a plasma of nuclei and electrons. However the electrons are as compact as they can be. This is the same force that prevents solid matter from passing through itself, but here, it applies to the whole white dwarf remnant at once: An atom as massive as a star. For some facts, a white dwarf remnant, has the mass of up to 1.4 suns, and a radius of a planet or moon.

Since many sun like stars can come from the same fragmenting nebula, it is very common for this generation of stars to orbit in pairs, and rarely triplets. This allows for a new phenomenon to occur. With an orbiting pair of sun like stars, one might form a planetary nebula first, before the other star even expands out to become a red giant. When the red giant's atmosphere touches the other white dwarf remnant, it captures lots of gas and dust. The nuclei slam onto its surface, and sometimes can temporarily cause nuclear explosions called novae. However, once the white dwarf remant starts to fuse elements into Iron-56, the same element that kills massive stars one by one, the remnant detonates. The resulting shockwave shreds the other star down to a cloud of plasma. This is called a type Ia supernova. The energy from such a supernova explosion outshines the rest of its galaxy for many weeks. Since every white dwarf remant always reaches the same mass before they explode, each exploding white dwarf remnant always has the same luminosity. A standard candle if you will…

The resulting type Ia supernova contains: 2 silicon-28 nuclei, 1 sulfur-32 nucleus, 1 argon-36 nucleus, and 3 iron-56 nuclei. Although iron as a nuclear fuel, is a star killer, most of the iron in the cosmos comes from supernovae like these. The gases and dust grains disperse into the interstellar medium.

We zoom back out to the intergalactic scale once again. At this point the three main spiral galaxies are about to merge together. In front of us is the Milky Way galaxy. A barred spiral galaxy about 100 thousand light years across. 2 million light years, over to the left is the grand spiral galaxy: Andromeda. It is 250 thousand light years across. Another 800 thousand light years, further left of the Andromeda galaxy, is a much smaller pinwheel galaxy: Triangulum. This galaxy is 70 thousand light years across. However, as time passes in the tens of billions of years, the Milky Way galaxy and Andromeda galaxies approach one another, spinning through space, in a knife edge configuration. During their collision, they pass right through each-other, flinging their guts millions of light years into space. Meanwhile, the Triangulum galaxy, shoots right through the crime scene at a relatively high speed. The seemily double spiral galaxy with two long tails, gradually reforms itself into a new conglomeration of old stars known as

an elliptical galaxy. The remants of the two tails continue to get eaten up by the newly formed elliptical galaxy's immense gravity. The Triangulum galaxy, comes back into the scene and is absorbed into the new Milkomeda galaxy. A slightly flattened eliptical galaxy, known as a lenticular galaxy.

The last stars to form are red dwarf stars: stars smaller than the sun, and far dimmer. Their surface temperature is around 3500 degrees, and are about a quarter of what was our sun's mass and radius. They steadily fuse hydrogen-1 into helium-4, over a great timespan. The first of these stars will only fade after many trillions of years into the future. Most red dwarf stars, come in pairs, triplets, or even larger solar systems. Again this is due to the fragmenting nebulae. With much more dust, and plenty of turbulence, from previous supernovae, later and later generations of stars, will be smaller, and more numerous. By then, the milkomeda galaxy, will just be a universally spread out galaxy, with stars receding away from one another faster and faster. Due to a cosmic vacuum expansion, driving the acceleration of the universe's expansion history. It isn't long until a red dwarf star sits there in the whole universe, completely isolated, no record of the big bang, no other matter or stars that can even reach us from here. After these stars fade is the universe over. What remains is an ever expanding vacuum of empty space!